DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

METALLURGICAL SMOKE

BY

CHARLES H. FULTON

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METALLURGICAL SMOKE.

By Charles H. Fulton.

INTRODUCTION.

One of the first matters to receive attention from the Bureau of Mines when it was authorized to undertake investigations relating to wastes in the mineral industries was the smoke problem at smelting and ore-roasting plants. This bulletin is published by the bureau primarily for persons who seek information on the subject of metallurgical smoke but are unacquainted with the technical language of metallurgy. It is, of course, not possible to free a technical subject entirely from technicalities, but, so far as possible, statements are made in plain and simple English.

Metallurgical smoke causes considerable friction between the metallurgical industry and agriculture in certain parts of the country. Owners of smelting plants are making every effort to devise ways and means to do away with possible damage and annoyance from smoke and are meeting with success. The problem is peculiarly difficult in this country because of the large tonnages of material that must be handled. The solution of the problem is not yet at hand and much work still remains to be done. As the mineral industry is one of the great basic industries of the country and of necessity is entitled to full consideration, it should be accorded freedom to work out the smoke problem to the benefit of all concerned. The effort is made in this paper to present the problem of metallurgical smoke as it actually exists, without bias of any kind.

The writer takes this opportunity to express his indebtedness to the sources of information on which he drew, many of which are enumerated in the selected bibliography at the end of this paper. In connection with the author's use of the present tense in describing plants and methods, the reader should note that none of the references in that bibliography is of later date than 1913. Much information was obtained by personal visits and by correspondence, and thanks are hereby tendered to all persons who kindly furnished data. The writer desires to thank particularly F. G. Cottrell, chief chemist of the Bureau of Mines, for criticism and comment.

GENERAL ASPECTS OF THE SMOKE PROBLEM.

DISTILLATION AND SUBLIMATION.

Distillation is a metallurgical process whereby a metal is converted into its vapor and then " condensed " if it collects in the liquid state, or " sublimed " if it passes directly from the vapor into the solid state without going through the intervening liquid condition. In the general sense " distillation " embodies both the vaporization from the liquid state and subsequent condensation of the metal again to liquid, whereas " sublimation " embodies the vaporization from the solid state and the subsequent sublimation to the solid state again, the liquid state not being passed through. Examples of distillation in metallurgy are the recovery of mercury from the ore, usually cinnabar (HgS), by heating in retorts or furnaces with free access of air, distilling the mercury as vapor, and cooling the vapor so that the metal is caught as liquid mercury in suitable receivers. Zinc is also obtained by distillation.

In some smelting operations one of the products is " fume." Thus, in lead smelting in the blast furnace, a part of the lead, 3 to 10 per cent, is volatilized in the furnace in the form of lead oxide and lead sulphide, with compounds of arsenic and antimony. These vaporized compounds of the metals pass with the furnace gases through the flues and dust chambers and thence out through the stack. When the temperature is low enough they sublime in the flues and chambers into finely divided solid material called " fume." This fume, however, is in many cases so exceedingly fine that it does not completely settle in the flues and chambers, but unless removed by filtering or in some other way it is carried out of the stack with the gases.

For these reasons the following usage has been adopted in this bulletin:

" Distillation " involves (1) the vaporization of the substance, and (2) the " condensation " of this vapor into a liquid. " Sublimation " embodies (1) the vaporization of a substance, and (2) the " subliming " of the vapor into fine solid particles without the intervening liquid stage being passed through. The word " condense " when used in this connection is therefore associated with the liquid state, whereas the word " sublime " is associated with the solid state. Thus when it is stated that the fume is condensed and sublimed it means that there are produced from the vapor state both minute liquid particles and minute solid particles.

COMPOSITION OF SMOKE.

In this bulletin the term " metallurgical smoke " is applied to the gases and vapors, and the fine dust entrained by them, that issue from the throat of furnaces, such as blast furnaces, reverberatory smelting furnaces, or roasting furnaces. At some plants the amount of metallurgical smoke is very great, exceeding in weight that of the solid material charged into the furnaces. Thus, in pyritic smelting, 1 ton of furnace charge requires approximately 1.2 tons of air to smelt it and gives rise to 1.4 tons of metallurgical smoke or furnace gases. Also, the volume of this smoke in the highly heated condition (400° C.) in which it is discharged from the furnace is very large. In the instance cited it is about 71,620 cubic feet per ton of charge. As an example of the tremendous amount of metallurgical smoke produced by a large smelting plant, data regarding the Washoe smelter at Anaconda, Mont., are given. That plant, which produces about 300 tons of copper a day, has a stack 30 feet in internal diameter at the top, which discharges 1,341,000,000 cubic feet of smoke per 24 hours, as measured at standard pressure and temperature. The smoke contains about 1.734 per cent by volume of sulphur-dioxide gas, or 23,252,940 cubic feet per 24 hours, which is equivalent to 2,092.7 tons, and, if converted into sulphuric acid, would yield 3,427 tons of acid, with a specific gravity of 66° B., or about one-third of the total production in the United States.

The volume of smoke discharged from the top of a stack is, of course, decidedly larger than that discharged at the throat of the furnaces of the plant, for in its passage through the dust chambers and flue system the smoke mixes with air that filters in accidentally or is purposely admitted.

GASES IN SMELTER SMOKE.

Metallurgical smoke consists of three distinct substances—the gases, the flue dust, and the fume. Of these three constituents the gases make up the great bulk. They come from the air used in the furnace to burn the fuel and also from chemical reactions between the oxygen of the air and certain constituents of the charge. The most abundant gas is nitrogen, derived from atmospheric nitrogen, which passes through the furnaces unaltered. It constitutes usually from 60 to 87 per cent of the bulk of metallurgical smoke. The gas ranking next in importance is carbon dioxide, which is produced by the combustion of carbon. The proportion of this gas ranges usually from about 3 to 5 per cent in pyritic smelting to about 15 to 20 per cent in lead blast-furnace smelting, being between these figures for other types of blast-furnace and reverberatory-furnace smelting. Gases from furnaces for roasting sulphide copper ores usually contain only insignificant amounts of carbon dioxide, but those from furnaces roasting lead ores and gold and silver ores in which carbonaceous fuel is burnt contain appreciable amounts of it. Carbon monoxide, a very poisonous gas, is not present to any degree in metallurgical smoke arising from the treatment of lead, copper, gold, and silver ores, the only exception being the gases from lead blast-furnace smelting, in which, on account of the considerable amount of fuel used, 5 to 10 per cent of carbon monoxide is found. Otherwise, the content of carbon monoxide rarely exceeds 1 per cent and sometimes is much less, none at all being present in gases from pyritic smelting and from certain roasting furnaces.

SULPHUR DIOXIDE.

The gases so far discussed are the constituents of smelter smoke that came no complaint and are the same as those that issue from the ordinary boiler stack. Sulphur dioxide is the constituent that largely gives smelter smoke its annoying properties, and requires special attention in order to be rendered innocuous.

In both roasting and smelting furnaces the sulphur dioxide is from the combustion of the sulphur in the sulphide minerals of the ore charge. The proportion of the gas in metallurgical smoke varies widely. The maximum amount of sulphur dioxide is found in the gases from pyritic smelting, where it constitutes 4½ to 9 per cent by volume of the smoke issuing from the furnace throat. In partial pyritic copper smelting the gases contain 2 to 3½ per cent of sulphur dioxide. The gases from the roasting of sulphide copper ores contain about 2 to 2.75 per cent, and may contain more. Gases from reverberatory smelting furnaces contain usually less than 0.5 per cent of sulphur dioxide, except in the early stages of smelting, during charging. Gases from lead-smelting furnaces and from the roasting of ores, not mentioned above, contain smaller proportions, usually less than 1½ per cent. These figures refer to the gases as discharged from the furnaces. Before the gases pass off into the atmosphere from the stack, they are usually considerably diluted. Formerly metallurgical smoke containing 1.5 per cent and more of sulphur dioxide was frequently discharged from stacks at some plants, but at present, in consequence of a number of court decisions, this proportion is reduced by dilution before the smoke reaches the stack. Some recent court decisions have fixed the amount of sulphur dioxide that may be discharged from stacks in certain districts at not more than 0.75 per cent.

SULPHUR TRIOXIDE.

Another gas found in metallurgical smoke, as it issues at high temperature from the furnaces, is sulphur trioxide or sulphuric anhydride. This substance, when combined with water, molecule for molecule, forms common sulphuric acid. It is formed in furnace operations by the oxidation of sulphide minerals, although in comparatively small amounts under most conditions, and if the temperature be high enough, the gas is found in the discharged gases, uncombined with water or with metallic bases, as sulphur trioxide. As the gases cool it combines with water, present in the metallurgical smoke as steam, to form sulphuric acid which, when the temperature becomes low enough, finally condenses. In this way sulphur trioxide in smelter smoke becomes an exceedingly harmful substance, one that may do a great deal of damage. Fortunately, however, it is present only in small proportions and, unlike the true gases, can be, and in most instances is, removed from the smoke before it is discharged into the atmosphere. Usually gases from blast-furnace smelting of copper and lead ores contain insignificant amounts of sulphur trioxide, but gases from roasting furnaces may contain appreciable proportions. Thus, for instance, gases from the roasting of sulphide copper ores may contain 0.25 to 0.75 per cent of sulphur trioxide. Aside from the gases mentioned, metallurgical smoke contains considerable water in the form of steam and occasionally small quantities of hydrocarbons and other gases.

FLUE DUST IN SMELTER SMOKE.

The flue dust that is carried by the gases as they issue from the furnaces consists of small particles of the different ores, fluxes, or fuel. The gases, on account of their high velocity, entrain these fine solid particles, and when the velocity is reduced in the dust chambers the particles settle. The amount of flue dust made in different smelting operations varies greatly, depending on such factors as design of furnace, fineness or coarseness of the ore charge, blast pressure or draft employed, and working condition of the furnace. Estimated on the basis of the tonnage of charge that is smelted, it may range from a fraction of 1 per cent up to 10 per cent of the weight of the furnace charge. Thus, in copper blast-furnace smelting at the Copper Queen mine in Arizona, 1 ton of flue dust was produced for every 17 tons of charge, or 5.55 per cent. In some instances, it is convenient to express the amount of flue dust in metallurgical smoke in the manner that iron metallurgists state the content of dust in blast furnace gas, that is, in grains (weight) per cubic foot of gas. This manner of expressing the dust content of the smoke stream is particularly applicable after the settling of the coarser particles.

Generally speaking, the composition of the flue dust is similar to that of the ore charge of the furnace. However, it may be modified by some constituents of the charge being finer than others and thus producing more dust. Flue dust is usually considered a troublesome product, for its treatment is rather difficult and expensive, although a number of successful methods have been devised. Flue dust varies in size from 0.25-inch to 0.125-inch particles of the lighter material down to an extremely fine dust resembling impalpable powder. No matter what its size, however, true flue dust is to be considered as composed of original particles of the ore charge, either unaltered or chemically changed. Its precise composition is discussed in some detail on pages 27 and 28.

FUME IN SMELTER SMOKE.

Related to the flue dust and in part recovered with it is the fume. Sometimes no distinction is made between fume and flue dust, for in copper smelting the amount of true fume is relatively small although certain plants treating arsenical ores make considerable fume. In lead smelting, however, considerable amounts of fume are produced. The fume consists of the volatile constituents of the ore charge which pass off in the form of vapor with the gases from the furnaces and then sublime into minute solid particles in the cooler part of the flues. In examining the dust chambers and the flue system of a smelting plant, it will be noted that a fine gray-white impalpable powder is deposited on the walls, roof, and floor of the flues near the stack end of the flue system, the amount being greatest near the stack and diminishing as the furnace is approached. In certain sections of the flues and chambers this fume is mixed with the fine flue dust.

On chemical examination, the fume is found to consist largely of lead compounds—such as the sulphate, sulphide, and oxide—arsenious oxide, antimony oxide, zinc oxide and zinc sulphate, elemental sulphur, and small amounts of the oxides of tellurium and selenium. In general, all the volatile constituents of the ore charge are represented. The fume frequently contains appreciable amounts of silver, which is markedly volatile under certain conditions. The particles of fume are very fine and are under the stress of certain physical forces, so they do not settle easily, as most of the flue dust does, but in large proportion pass through the stack with the gases and spread over the surrounding country, unless special preventive methods are applied, as is now generally done.

When zinc minerals are present in the furnace charge, sulphur trioxide is rendered harmless in so far as the formation of sulphuric acid is concerned, as sulphur trioxide unites with zinc oxide to form sulphate of zinc, which is deposited with the fume. Lead minerals act similarly to zinc minerals, when the action in the furnace is oxidizing. The most harmful constituents of true fume, if allowed to escape from the stack, are sulphuric acid, lead compounds, and arsenious oxide. These substances settle on the surrounding country and under certain atmospheric conditions of moisture and wind may sufficiently concentrate to damage vegetation and injure animal life

Most of the more modern metallurgical plants make ample provision for the recovery of fume from furnace smoke. Stacks from metallurgical works sometimes emit white or grayish-white smoke of varying degrees of density, from smoke that is barely visible to very dense smoke. In general one may state that it is the fume that renders metallurgical smoke visible, except when visibility is due to the condensation of water vapor on cold days. The true gases in metallurgical smoke are invisible.

From the foregoing statement it is evident that metallurgical smoke contains three distinct types of constituents—gases, flue dust, and fume. Of these, all the true gases escape from the stack, and all but the very finest flue dust may be settled out by ample and properly designed dust chambers. The fume is only partly recovered with the flue dust even by the use of elaborate dust chambers and flues; special apparatus must be erected to recover it.

HARMFUL CONSTITUENTS OF METALLURGICAL SMOKE.

It is apparent that the harmful constituents of smelter smoke are: (1) Sulphur dioxide gas, (2) sulphuric acid formed from sulphur trioxide generated in the furnaces, (3) fume or fine solid particles containing lead and arsenic compounds and acid sulphates.

SULPHUR DIOXIDE.

The most important of these at the present time is sulphur dioxide, for no universally applicable method of eliminating this gas from smelter smoke is as yet in commercial use. Sulphur trioxide and sulphuric acid in their behavior may be classed with true fume, and methods can be used that will completely eliminate these substances from the smoke before it is discharged into the atmosphere. Sulphur dioxide is therefore considered first.

SULPHUR DIOXIDE IN AIR.

Sulphur dioxide is an invisible gas with a highly characteristic penetrating and pungent odor familiar to almost everyone. It is stated that air containing 0.007 per cent by volume of this gas is unbreathable, the gas not having a toxic effect but causing a spasmodic contraction of the air cells of the lungs. Only very small proportions of the gas are ordinarily present in the atmosphere, but measurable quantities are invariably found in the air of cities, especially manufacturing centers where much coal is burned, being formed by the combustion of the sulphide minerals in coal, all coal containing some sulphur. As an example of the quantity of sulphur dioxide in the air of cities, the following examples are given: Berlin, 0.000035 per cent by volume; London, 0.00039 per cent; Glasgow, 0.00042 per cent. Air in the vicinity of Salt Lake City, Utah, contained from 0.001 per cent to none.

The gas may be detected in the air by its smell if present in the ratio of more than one part to 150,000 parts of air. Chemically, it may be readily detected in the air when the proportion present is more than one part per million. It is probable that the sulphur dioxide of the air is slowly converted into sulphuric acid by the action of the oxygen and the water vapor in the air, and is finally precipitated with the rain or snow.

EFFECT OF SULPHUR DIOXIDE ON VEGETATION.

All vegetation is not equally affected by the sulphur dioxide in the air. It is stated on good authority that the soft, resinous woods, especially spruce, are most readily injured, one part of sulphur dioxide in 500,000 parts of air doing damage if permanently present. One part in 500,000 is equivalent to 0.0002 per cent by volume or to 0.0071 grams of sulphur dioxide per cubic meter of air. The trees most resistant to the action of sulphur dioxide are the hardwoods, such as oak and maple. There are comparatively few reliable data as to the precise effect of sulphur dioxide and the amount that is necessary to damage different varieties of plants.[a] In recent litigation in this country on smelter smoke, much expert testimony was offered by both sides. That this evidence would be contradictory was to be expected with the present systems of taking expert testimony, and, for evident reasons, much of the evidence had no practical or scientific value.

The prevention of damage to vegetation by sulphur dioxide in the atmosphere needs the close study of disinterested scientific observers. It is probable that the question will be prominent for some time, as the elimination of sulphur dioxide from smelter smoke seems to be in the far future, and the amelioration of conditions depends at present on diluting the smoke until the sulphur dioxide content is so small as to be harmless. This in itself is a great engineering problem for large plants. The point to which dilution must be carried no doubt depends upon the nature of the vegetation in the vicinity of the plant, the climate, whether wet or dry, and the season of the year. It has been found in Europe and in Japan that some crops are much more subject to injury at certain stages of their growth than at others, and proposals have been made to put seasonal limitations on the tonnage of sulphide ore smelted. An agreement of this kind is in effect in southeastern Tennessee and also in Japan. During the active crop-growing season the amount of high sulphur-bearing ore smelted is reduced, and is again increased during the fall and winter months.

That comparatively small amounts of sulphur dioxide and sulphuric acid (it must be borne in mind that sulphur dioxide is probably slowly converted into sulphuric acid in the atmosphere) do harm to vegetation is attested to by an examination of the trees in large industrial cities. These, although in many instances seemingly healthy, suffer from sulphate poisoning and lose their leaves much earlier in the fall than other trees in the vicinity not subject to the contaminating atmosphere.

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[a] For a full discussion, see Report of the Selby Smelter Commission, 1915.

Sometimes, in discussions of the smelter-smoke question by interested parties, gross misstatements of fact are made. Thus, the agriculturist sees bad effects from smelter smoke which other people can not find, and the metallurgist sometimes goes so far as to claim that smelter smoke is beneficial to vegetation, and even to assume that the damaging constituent of smelter smoke is sulphur trioxide only, giving rise to sulphuric acid, and to ignore entirely the sulphur dioxide content. It is evident that nothing is to be gained by a policy of this kind, and the solution of the problem lies in its study by disinterested commissions, such as the one recently appointed by an agreement between the Department of Justice and the attorneys of the Anaconda company to study the smoke question in Montana in its relation to the forest reserves.

COMPARISON OF SMELTER-SMOKE PROBLEM IN EUROPE AND THE UNITED STATES.

The problem of damage by smelter smoke has been rather closely studied for many years in European countries, particularly in Germany, and it might seem as if profit could be derived from this study and experience. Although this is true to some extent, a closer study of the question shows that conditions in Europe and in this country are widely different. At European plants the amount of sulphide ores smelted, and hence the volume of fume discharged from furnaces there, is small as compared with those at plants in this country. Moreover, methods for handling smoke that are satisfactory for small operations are inadequate and unsatisfactory for large-scale work. For example, relatively small amounts of smoke may be put through a washing process and most of the deleterious constituents removed, but such washing is impracticable for very large volumes of gas. Even in European countries where it would seem that the question might have been settled long ago, contention between metallurgical and agricultural interests is not infrequent. Evidently the problem is inherently difficult to solve in a satisfactory manner.

SMELTER-SMOKE PROBLEM IN THE WESTERN STATES.

It is interesting to review the general situation in this country. Much of the trouble is in the Western States, and chiefly in Montana, Utah, and California. In those States very large tonnages of sulphide ores are smelted with the production of great volumes of smelter smoke, comparatively rich in sulphur dioxide and other injurious constituents. A number of the smelters have been in operation for many years and have experienced difficulties only comparatively recently.

It is well known that mining and metallurgy are often the advance agents of civilization and the pioneers in establishing industrial centers. In many localities the mines and the smelters supplied by them were essentially the only locators within great stretches of territory. Around them grew communities and cities dependent upon them for a livelihood. Agriculture was of relatively small importance. But conditions changed with the increasing population of the country and the closer settlement of the West and, coincident with this increase, an agricultural industry has grown which, in the vicinity of the smelting plants, naturally suffers in some degree from smoke. Still, the area damaged is comparatively small and even this damage can be much lessened by the adoption of proper means. Since some plants have installed devices to remove sulphuric acid from the smelter smoke and have the smoke diluted with air, conditions have been much ameliorated in certain districts.

EFFECT OF CLIMATIC CONDITIONS.

The damage that smoke can do depends largely on climatic conditions, especially the relative humidity of the atmosphere. The damage is much greater in regions having a moist than in those having a dry climate. In this respect such States as Montana, Utah, and Arizona are favorably located and smelters in those States can probably discharge gases richer in sulphur dioxide without doing damage than those in regions having a moister climate. For the same reason, the damage done at different seasons of the year varies. The moist atmosphere and the rains of spring and early summer conduce to increase damage to vegetation, particularly as at that time of the year the early crops and young vegetation are susceptible to serious injury.

It has been customary to discharge the smelter smoke by means of very tall chimneys, on the assumption that if the noxious gases are discharged at considerable height they will have opportunity to diffuse more thoroughly and thus become so diluted as to be comparatively harmless, but the efficiency of this method is now being questioned. There is reason to believe that the use of high stacks increases the area subject to damage, whereas low stacks may intensify the damage but concentrate it within a smaller area. Probably high chimneys do not serve their purpose as well as was anticipated, and perhaps at present the better method may be to dilute the smelter smoke and discharge it from a number of stacks.

SMELTER SMOKE IN LARGE CITIES.

In reference to smoke and damage suits by agricultural interests in western States, the statement is sometimes made that it is not apparent why these plants should be complained of, when within such cities as Omaha, Chicago, and New York there are large smelters and metallurgical works that discharge smelter smoke. The answer to this statement is to be found in the fact that none of the metallurgical plants near these cities treats any considerable tonnage of high-sulphur ores. Most of the smelters so situated are refining plants, which may smelt some sulphide ores, but not in sufficient amount to cause trouble from sulphur dioxide. It frequently happens, too, that there is serious complaint in cities concerning the smoke nuisance and damage from metallurgical plants. For instance, Staten Island, N. Y., sometimes suffers inconvenience, if not damage, from certain large metallurgical plants in New Jersey. This inconvenience, however, is not caused by sulphur dioxide, so far as the writer knows, but rather by fume and, in certain cases, fine flue dust. Such conditions as these are comparatively easy to remedy.

THE THREE MAIN CONSTITUENTS OF METALLURGICAL SMOKE.

Metallurgical smoke is here discussed in detail in relation to the three main constituents of smelter smoke—gas, flue dust, and fume. In practice it is difficult to sharply differentiate flue dust and fume. Smelter smoke issuing from the throats of furnaces contains all three constituents. The flue dust, consisting of the solid particles entrained by the gases, settles as the velocity of the gas stream diminishes, all except the very fine particles, which may not settle even in the lowest velocity that the gas stream attains in its passage through the flues and dust chambers. Certain metallic vapors that form in the furnaces, as for instance, arsenious oxide, lead sulphide, and zinc oxide,[a] are carried as true vapors in the smoke at high temperature, and then, as the smoke passes to the cooler parts of the flue system, they sublime as very small particles of fume. As an illustration the following example is given. If solid arsenious oxide be placed in a vessel that is open to the air at normal pressure (760 mm. of mercury), and then heated, it sends off into the space above it arsenious oxide vapor, which in part replaces the overlying air. Before the arsenious oxide is heated the pressure overlying it (760 mm.) is due solely to the air. After the heating however, although the total pressure is still 760 mm., part of the pressure is due to the vapor of arsenious oxide, which has replaced a certain amount of air. The pressure making a part of the total pressure overlying the solid is termed a "partial pressure," and is due to the vapor tension of the solid at the existing temperature. The vapor tension varies with the temperature. Vapor tension is small at a low temperature, and increases as the temperature rises.

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[a] Zinc oxide is not markedly volatile except at high temperature. Under certain furnace conditions, however, zinc and zinc compounds vaporize, and these vapors are converted into oxide fume when they come in contact with atmospheric oxygen.

PRECIPITATION OF SMOKE PARTICLES.

EFFECT OF VAPOR TENSION.

A substance boils when its vapor tension becomes equal to the pressure above it. If a volume of gas that has been in contact with solid arsenious oxide at a certain high temperature, and hence is saturated with arsenious vapor, be removed and passed with other gases to cooler parts of a flue system, arsenious oxide will sublime or precipitate in very fine solid particles, because, with a falling temperature, the vapor tension of the arsenious oxide diminishes and part of the oxide sublimes into the solid state.

An analogous case is that of water vapor. If water overlain by air be heated, water vaporizes as steam, which will mix with the air above it in the same manner as the arsenious oxide mentioned above. If this vapor-laden air be removed from above the water and passed to regions where the temperature is lower, water will precipitate or condense from the air in the shape of fog or rain. Air ordinarily contains water vapor, the amount being dependent on the temperature. If, for a given temperature, the air holds all of the water vapor possible, it is said to be saturated. When saturated air cools water is precipitated. For every given temperature the air has a definite saturation point as regards water vapor. If the amount of water in a given volume of air is not sufficient to saturate it for the temperature existing, and it is then cooled, water will not precipitate from the air until a temperature is reached that represents the saturation point for the amount of water vapor present.

These principles govern the condensation and sublimation of liquid and solid particles respectively from their vapors carried in gas streams. In metallurgical smoke, they are particularly applicable to water vapor, sulphur trioxide, sulphuric acid, arsenious oxide, zinc oxide, lead sulphide, etc. At the high temperature in metallurgical furnaces, these substances are vaporized and pass into the smoke stream, but usually the smoke stream does not become saturated with any of them, as they are present in quantities much below the saturation point for the existing temperature. Then, as the smoke stream passes into the flues and cools, the saturation point for the existing temperature of some of the substances is reached, and they begin to precipitate either as fine solid particles of fume, such as arsenious oxide and lead oxide, or as fine particles of liquid, as, for instance, sulphuric acid.

NEED OF COOLING THE GASES.

It is evident from the foregoing statement that in order to separate from the smoke stream the substances that make the true fume, it is necessary not only to decrease the velocity of the gases, but also to cool the gases to such a point that practically none of the substances can continue to exist in the vapor state. To remove both true flue dust and fume it is necessary to cool the smoke stream to a comparatively low temperature and to reduce the velocity of the stream until it is low. On considering the ordinary flue system of a smelting plant, beginning with the connecting flues from the furnaces and then considering in order the enlarged dust chamber, the flues to the chimney, and the chimney itself, it will be found that the temperature gradually diminishes from the furnaces to the chimney and that the velocity of the smoke stream is higher near the furnaces, where the gas volume is greatly increased by the high temperature, and is lowest in the dust chamber where the cross-sectional area is such as to produce a minimum linear velocity. In the flue system near the furnaces, the temperature is too high for any fume to be precipitated. In the dust chamber, where a lower temperature prevails, the flue dust, consisting of certain small particles of the ore charge and some fume, is deposited. Toward the chimney the size of the flue-dust particles decreases and true fume commences to appear, the proportion increasing as the chimney is approached. Therefore, in certain sections of the flue system, the solids that settle from the smoke stream are a mixture of true flue dust and fume. and the ratio of fume to flue dust increases toward the chimney.

In taking samples of settled solids from different parts of the flue system, it is not possible to state that one material is flue dust and another material is fume, for in nearly all samples the flue dust and the fume are mixed. A ready distinction between the flue dust and fume can, however, be made by means of chemical analysis. The flue dust, as already stated, consists of solid particles of the furnace charge which have been carried over into the flue system by the velocity of the gases. An invariable constituent of the furnace charge is silica, so that flue dust always has a high content of silica or insoluble matter. Fume, on the other hand, consisting as it does of condensed metallic vapors, is essentially free from silica, so that practically a silica limit might be established to differentiate between flue dust and fume. Material above 5 per cent silica could be termed "flue dust" and material below that "fume." This distinction is further discussed elsewhere (pp. 27 to 36).

The gases present in the smoke, chiefly nitrogen, oxygen, carbon dioxide, and sulphur dioxide, pass from the stack to the atmosphere. The difference in state between these gases and the metallic vapors existing at the high temperature near the furnace is one of degree only. The vapors can be condensed or sublimed at relatively high temperatures, but the gases can be condensed only at much lower temperatures. To condense nitrogen, oxygen, and carbon dioxide to the liquid state is, of course, out of the question, and entirely unnecessary to consider in this instance, but the condensation of sulphur-dioxide gas to a liquid merits attention, and is considered in subsequent pages.

GASES IN METALLURGICAL SMOKE.

The common gases in metallurgical smoke are nitrogen, oxygen, sulphur dioxide, carbon dioxide, sulphur trioxide, and carbon monoxide; occasionally hydrocarbon gases are present in small amounts. At high temperatures, water in the form of vapor is usually present. As the gases issue from the throats of blast, reverberatory, and roasting furnaces, they always become somewhat diluted by what may be termed "false air," and the amount of such dilution increases from the furnace throat to the stack, being dependent on the tightness of dust chambers and flues and on the intentional admission of false air to cool the gas stream or to lower the percentage of some of the deleterious constituents, such as sulphur dioxide. This dilution, of course, changes the volume composition of the gases, although it does not change the total weights of certain constituents, such as sulphur dioxide, that are emitted from the flue and stack system.

The composition of smelter gases therefore varies somewhat with the point of sampling in the flue system. The accompanying table gives the results of analyses of typical smelter gases at a western copper smelter.

Table 1.—*Composition of furnace gases.*

[In percentage of volume, at 0° C. and 760 mm. pressure.]

Constituent.	Part of flue system.				
	Flue from roasting furnaces.	Flue from blast furnaces.	Flue from converters.	Flue from reverberatory furnaces.	Flue at base of stack.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Sulphur dioxide	2.545	1.274	2.845	0.423	1.164
Sulphur trioxide	.275	.086	.0505	.0044	.0395
Carbon dioxide	.1136	6.493	.2084	5.242	2.748
Water vapor	2.784	3.490	1.061	3.869	2.834
Arsenic trioxide	.0073	.0091	.00073	.0156	.00465
Oxygen	14.02	10.18	12.04	10.37	11.88
Nitrogen	81.18	78.13	83.64	79.57	80.73
Carbon monoxide	None.	None.	None.	Trace.	None.
Total	100.90	99.70	99.80	99.50	99.40

The samples corresponding to these analyses were taken from the flues and represented the furnace gases, diluted to a considerable degree with false air. It will be noted that the sulphur dioxide, as well as the other constituents of the samples, varied considerably in the gases from the different furnaces.

It is unnecessary to discuss the properties of the smelter-smoke gases—carbon monoxide, carbon dioxide, nitrogen, and oxygen—as these have no particular bearing on the problem in hand. Carbon monoxide is a highly poisonous gas and of much importance in the gases issuing from the iron-blast furnace, but it is found in small amounts only in gases from furnaces such as are under discussion, with the exception of the lead-blast furnace, the gases from which may contain as much as 10 per cent of carbon monoxide.

SULPHUR DIOXIDE.

CHARACTERISTICS.

The gases of most importance in the smoke stream are sulphur dioxide and sulphur trioxide. Sulphur dioxide is an irritant gas with the powerful odor characteristic of burning sulphur. If pure sulphur dioxide gas not admixed with other gases be cooled to —10° C. at ordinary atmospheric pressure (760 mm. of mercury, or 14.5 pounds per square inch), it condenses to a mobile liquid. If the temperature be further lowered to —76.1° C. the liquid freezes to a white snowlike mass. At any temperature between these two, gaseous sulphur dioxide will still exist above the liquid dioxide, the amount of the gaseous dioxide being dependent on the temperature. Even below —76.1° C. some gaseous sulphur dioxide will exist, as the solid dioxide has a vapor tension, although small.

CONDITIONS GOVERNING CONDENSATION.

If smelter smoke containing 2.5 per cent of sulphur dioxide by volume be considered at ordinary atmospheric pressure, the partial pressure, or that part of the whole atmospheric pressure due to the 2.5 per cent of sulphur dioxide, will be equivalent to 19 mm. of mercury. Before any of the sulphur dioxide can be condensed to the liquid form the smelter smoke will have to be cooled to that temperature at which the vapor tension for saturation is less than 19 mm. of mercury. At —30° C. (the lowest temperature for which data are at hand) the saturation vapor tension of sulphur dioxide is still 273.6 mm. of mercury. This corresponds to 36 per cent by volume of sulphur dioxide in the smoke stream. Therefore, even if the smoke stream considered at atmospheric pressure were cooled to —30° C., it would have to contain at least 36 per cent of sulphur dioxide before any condensation of the dioxide could begin. It is hence evident that mere cooling of smelter smoke, even to very low temperatures, will be without effect on the sulphur dioxide content of smelter smoke. However, if pressure be applied to the smoke at the same time that it is cooled, condensation of the sulphur dioxide can be brought about. As already stated, for —30° C. the saturation vapor tension of sulphur dioxide is 273.6 mm. of mercury. Hence smoke containing 2.5 per cent of sulphur dioxide, which corresponds to a partial pressure of 19 mm. would have to be compressed 14.4 atmospheres ($\frac{273.6}{19}$) before the sulphur dioxide would begin to condense into liquid particles. The cooling of enormous volumes of smelter smoke to low temperatures and compression to a high degree would be so costly as to make this suggested method of eliminating sulphur dioxide from smoke entirely impracticable.

Another method proposed is that of refrigerating the gases and freezing out sulphur dioxide in connection with the water vapor. There are possibilities in this process, and it is again mentioned in a subsequent section.

EFFECT OF SULPHUR DIOXIDE ON MEN AND ON VEGETATION.

The effect of sulphur dioxide on the human system has already been briefly mentioned. Seventy parts per million make air containing it unbreathable. Some authorities hold that it is distinctly harmful, others that although its effect is highly disagreeable, and of course not beneficial, the harm done by it is not serious. It is always present in readily noticeable quantity in the air about copper-smelting and roasting furnaces; in fact, to such an extent, that the ordinary visitor to these plants finds the atmosphere practically unbearable. Furnace men, however, work in this atmosphere continuously and do not seem to suffer permanent harm from their contact with the gas. On the other hand, the effect of the gas on vegetation is seriously harmful. The proportion that does damage has been mentioned, as also the fact that different types of plants and even different plants of the same species are not affected alike.

A summary of the action of sulphur dioxide on plants may be stated as follows: The action shows itself by spots on the leaves, the whole leaf sometimes becoming seared and yellow. This drying of leaves and twigs and the falling behind in yearly growth give the general appearance of a dying plant. The severity of the symptoms varies with the proportion of sulphur dioxide in the atmosphere. The sulphur dioxide causes a derangement of the water circulation, leading to loss of water, thus causing the drying of the leaves. Practically all damage to plants by the gas is by action on the leaves and bark, but chiefly on the leaves. The gas is absorbed by the leaf surface as a whole, probably acting on the chlorophyll in the leaf, sulphates eventually being formed. There is no direct action either by sulphur dioxide or sulphur trioxide on the roots of plants, and hence no indirect action through the soil. It is generally conceded that the soil is not injured by sulphur dioxide or sulphur trioxide either acting directly or dissolved in the rain. The action of sulphur dioxide on the life of the plant is intensified by light and high temperature, and by moisture in the air. Plants in damp climates or climates in which fogs occur are much more subject to damage than those in dry climates. This statement is somewhat in dispute, but from the writer's own experience, he is inclined to believe that the damage is greater in the presence of moisture than when moisture is practically absent.

Damage to vegetation can be shown by the increased sulphate content over the normal amount usually present. In this connection, however, it is necessary to take into consideration the sulphate content of the soil, as the percentage of sulphate in the leaves depends upon the nature of the soil. In general, conifers, or plants whose leaves are resinous are most easily injured. Certain species of pine, such as the white pine, may be injured by as little as one part of sulphur dioxide per million parts of air if this amount be constantly present. This tree may be severely injured or even killed when other trees show no injury whatever. The red fir is also easily susceptible to damage. Post oak, white oak, and the red maple are comparatively resistant to injury by sulphur dioxide. Junipers, although belonging to the conifer family, resist injury well. Black and Spanish oak, yellow pine, and lodge-pole pine are rather easily injured.

PROPORTION OF SULPHUR DIOXIDE IN AIR NEAR SMELTERS.

The proportion of sulphur dioxide gas in the atmosphere in the vicinity of smelters naturally depends upon the ore capacity of the plants and the amount of sulphur in the ores. A correct measure is the volume of smoke discharged by the stack and the sulphur dioxide content of this smoke. Data for one large plant have already been given. As damage to vegetation is done when the sulphur dioxide reaches a certain concentration in the atmosphere, it would appear that it is necessary under present conditions, with no practical process available for the removal of this gas from the smoke, to have this so diluted when it issues from the stack that the concentration necessary for damage is not attained. If the smoke as it issues from the top of the stack would rapidly and uniformly diffuse itself throughout the atmosphere, large volumes of smoke containing 1.5 to 2 per cent of sulphur dioxide might possibly be discharged with little damage to vegetation. Unfortunately the diffusion of smoke does not take place rapidly. The smoke, as it issues from the stack, has a rapid vortex motion, which seems to hold it together to some extent in masses after it leaves the stack. These smoke masses, which are rendered visible by the fume, are of the same general composition as the original smoke stream, although considerably diluted. It is a matter of common observation that smelter smoke issuing from a high stack will trail off for miles before it finally reaches the ground.

Some of the gases in the smoke stream unquestionably are diffused much more widely than is indicated by the visible fume of the stream. On the whole, however, the contents of the smoke stream tend to hang together in masses, and when these masses strike vegetation the damage is done. That this statement is true is attested by experience gained by the use of high chimneys. It is fairly well established that when high chimneys are used for discharging the smoke into the upper regions of the atmosphere in order to attain a more complete diffusion of the gases before they reach the earth damage still occurs, although distributed over a wider area and not so pronounced. This indicates the difficulty of a thorough diffusion or mixing of the gases with air.

Efforts have been made to obtain definite figures as to the sulphur dioxide content of the atmosphere in the vicinity of smelters. Data of this sort must always be considered with caution, for the results obtained depend largely on the location of the place where the sample is taken in reference to the stack and to the prevailing wind at the time. For, as the diffusion is so irregular, the place sampled might indicate at one time only traces of sulphur dioxide, whereas a few hours later the dioxide might be present in damaging proportions.

SULPHUR TRIOXIDE.

CHARACTERISTICS AND ORIGIN.

Sulphur trioxide is an oxide of sulphur of a higher degree of oxidation than sulphur dioxide and is the basis of the common oil of vitriol or sulphuric acid of commerce. It is formed to some extent in roasting furnaces and to a much lesser extent in other furnaces. The proportion in the smoke stream is never great, but even small quantities, if they be permitted to escape into the atmosphere, are very harmful. However, only with comparative infrequency does smoke discharged from smelter stacks contain more than small proportions of sulphur trioxide in such form as to do damage. Sulphur trioxide combines molecule for molecule with water to form sulphuric acid.

In order to comprehend the behavior of sulphur trioxide in the smoke, it may be followed from its origin in the furnace. If the roasting furnace be considered as the chief source of sulphur trioxide in the smoke, its origin is due to the formation of sulphates of iron, copper, lead, or zinc during the roasting process and the subsequent decomposition of these sulphates into the oxides of the metals and sulphur trioxide. When the sulphur trioxide is liberated by the decomposition of the sulphates, for which certain temperatures are necessary, it is in the form of a true gas and is carried in the smoke stream. The smoke stream also carries water vapor, the origin of which is the moisture in the ore charges fed to the furnaces. As long as the smoke stream has a temperature above 440° C., no combination of sulphur trioxide with water vapor to form sulphuric acid is possible, but as the temperature falls in the flues as the stack is approached, sulphuric acid vapor forms by the combination of water vapor and sulphur trioxide vapor, until at about 350° C. one-half of the sulphur trioxide present in the smoke stream is in the form of sulphuric acid vapor. At ordinary atmospheric pressure (760 mm.) sulphuric acid, or rather a mixture of 98.54 per cent of sulphuric acid and 1.46 per cent of water, has a boiling point of 338° C. From this it follows that above 338° C. all sulphuric acid present must be in a vapor form or dissociated, but that below this temperature it may be present in the smoke stream in the liquid form as a fine mist or small liquid particles. As sulphuric acid, like most other liquids, has a vapor tension below its boiling point, a certain proportion of it may still exist in the vapor form below its boiling point, the exact percentage being dependent on its vapor tension for any corresponding temperature. The vapor tension of sulphuric acid is generally considered to be practically zero at about 200° C.[a] The acid that condenses at this temperature has a gravity of about 1.75, corresponding to 62° B. Therefore, the conclusion can be made that with an excess of water vapor in the smoke, or more than is necessary to form sulphuric acid with the sulphur trioxide present, all of the sulphur trioxide in the smoke will be in the form of a mist of sulphuric acid at about 200° C.

FORM OF OCCURRENCE OF SULPHUR TRIOXIDE IN SMELTER SMOKE.

The influence of temperature on the conditions of the sulphur trioxide is indicated below:

Influence of temperature on the condition of sulphur trioxide in smelter smoke.

Temperature of smoke stream.	Condition of sulphur trioxide.
°C.	
440+	Free state, uncombined with water vapor.
350–440	About one-half combined with water as sulphuric acid.
338±	Combined with water as sulphuric acid, but in vapor state.
200–338	Sulphuric acid present partly as a condensed mist and partly as vapor, the relative proportions being dependent on the total proportion of sulphuric acid in the smoke stream.
200–	Sulphuric acid all in condensed form or as a fine mist or fume.

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[a] Very little definite information has been available as to the vapor pressure of sulphuric acid, and the discussion following is subject to correction when pertinent data become available.

As already stated the relations indicated in the table apply only when there is an excess of water vapor over and above that required to form sulphuric acid with all of the sulphur trioxide present. This condition invariably occurs in ordinary smelter smoke as may be seen from Table 1. Under certain conditions, however, the amount of water vapor present may be insufficient to form sulphuric acid with all of the sulphur trioxide. Somewhat different conditions may then exist, and free sulphur trioxide in the form of a fine mist or fume may be present in the smelter smoke. Sulphur trioxide vapor condenses into a liquid at 46° C., and freezes into a solid at 14.8° C. The liquid trioxide has, of course, a considerable vapor tension, so that most of the free trioxide in smelter smoke, owing to the small amount, will be in the form of vapor until the solidification temperature of 14.8° C. has been reached.

If the sulphur trioxide is present finally in the form of sulphuric acid, the latter will be deposited in part as a mist or fume in the flues and in part will be carried out the stack with the gases as a fume, provided there is nothing present in the smoke stream to act as a base to sulphuric acid and combine with it. In most instances, however, the smoke stream, at the time the sulphuric acid forms, will still carry some fine flue dust in which there is iron oxide, zinc oxide, copper oxide, lead oxide, etc. The fine dust, in intimate contact with the fine particles of sulphuric acid, will react and cause the formation of sulphates. The sulphates deposit with the flue dust.

Many smelter gases do not carry sufficient amounts of these reacting bases in the form of fine dust or fume at the time that the sulphuric acid is ready to combine with them, and hence, under such conditions, sulphuric acid may be discharged from the stack. When the ore charge smelted or roasted contains a considerable percentage of volatile metals such as lead, zinc, and cadmium, these partly pass to the fume and, under oxidizing conditions, form oxides. The fine fume particles combine readily with the sulphuric acid formed, giving rise to sulphates and the consequent neutralization of the acid. The neutralization or the formation of sulphates probably does not readily take place until temperatures below 200° C. are reached, meaning practically that before sulphates are formed the sulphuric acid must be below its condensation point. The neutralization is probably effected by small particles of fume becoming centers of condensation for the acid. In most lead blast-furnace smelting the smelter smoke is filtered through a large number of long woolen or cotton bags, in order to recover from it all of the fine fume or solid particles and discharge only gases into the atmosphere. The smelter smoke when it reaches the bag house must fulfill two conditions: first, it must have a temperature low enough so as not to scorch the bags and injure their fabric, and, second, it must be essentially free from sulphuric acid, which rapidly corrodes the bags.

Both of these objects are accomplished by cooling the gases to about 100° F. for at that temperature no scorching can take place and the sulphuric acid will have condensed out. Neutralization in smoke from the lead blast furnace is imperfect, as the volatile metallic compounds are not oxides because the smelting is done under reducing conditions.

The gases from roasting furnaces, as already mentioned, contain more sulphur troxide than other furnace gases, and until recently it was considered impracticable to pass them through the bag house, for, as they did not contain sufficient metallic fume to neutralize the free sulphuric acid formed, their action on the bags was so destructive as to make filtering impracticable. However, by introducing into the smoke stream a comparatively large proportion of zinc oxide fume or finely powdered lime, the sulphuric acid can practically all be neutralized, if the temperature of the gases be low enough. The process is known as the " Sprague process " and is discussed elsewhere.

In order to compare the foregoing data with actual conditions, the following flue temperatures taken from practice are cited. At the copper smelter in Great Falls, Mont., the temperature at a certain point in the blast-furnace flue was 199° C. (393° F.) ; in the roasting flue it was 215° C. (419° F.) ; at the base of the stack it was 155° C. (311° F.) ; at the copper smelter at Anaconda, Mont., the temperature of the gases at the base of the stack in winter was 159° C. (318.2 F.). It would therefore seem that, under conditions such that a copper smelter discharges smoke, free sulphuric acid may be present, as the temperature of discharge is somewhat too high for complete neutralization to take place, even if enough metallic oxide fume be present.

FLUE DUST IN METALLURGICAL SMOKE.

COMPOSITION OF FLUE DUST.

Flue dust consists of the fine particles of furnace charge, either in their original condition or chemically changed, that have been carried into the dust chambers and flue system by the action of the furnace gases. True flue dust does not include fume. This consists of the metallic compounds that have been vaporized by the heat of the furnace and then sublimed or condensed by being subjected to cooling in the flues. From a practical standpoint, however, it is impossible to completely differentiate flue dust from fume for reasons already given. Tables 2 and 3 following give the results of incomplete analyses of flue dusts from Great Falls, Mont., and from plants near Salt Lake City, Utah.

TABLE 2.—*Results of incomplete analyses of flue dusts from smelter at Great Falls, Mont.*

Source of dust sample.	Composition.											Remarks.
	Copper content stated as metallic copper.	Silver.	Gold.	Insoluble constituents.	Silica.	Iron content stated as ferrous oxide.	Alumina.	Lime.	Total sulphur present as sulphide and sulphate.	Sulphur trioxide free and combined.	Arsenic trioxide.	
	P. ct.	*Oz.*	*Oz.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		
Experimental flue	6.20	3.4	0.025	38.2	26.0	7.32	13.3	0.80	7.10	1.410	Some	
Blast-furnace flue	8.08	2.7	.019	34.7	26.8	33.00	7.10	1.70	16.10	......	...do	
Roasting-furnace flue	10.22	3.6	.023	37.6	29.0	27.10	7.50	0.30	21.30	......	...do	
Main dust chamber	8.61	3.3	.020	33.3	23.6	14.5	8.00	.70	11.80	......	...do	
Base of chimney	2.21	......	......	8.4	5.4	3.8	2.8	.10	10.70	......	Considerable.	This may be considered as fume.

TABLE 3.—*Results of incomplete analyses of flue dusts from plants near Salt Lake City, Utah.*

Source of dust sample.	Moisture or water below 100° C.	Amount of sulphur trioxide present in water-soluble sulphates.	Total sulphur trioxide.	Amount of iron present in such form as to be soluble in water.	Total iron content stated as metallic iron.	Amount of copper present in such form as to be soluble in water.	Total copper content stated as metallic copper.	Insoluble SiO_2.	Lead.	Arsenic.	Zinc.	Remarks.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
Roasting-furnace flue.	0.01	6.7	20.6	0.20	8.10	Tr.	2.20	31.4	16.3	1.31	4.40	Sample taken from lead-smelter flue near stack.
Blast-furnace flue.	.70	2.3	31.8	None.	33.0	None.	3.70	27.4	2.4	.47	.95	Sample taken from copper smelter.
Dust concretion at top of a stack.	4.10	17.7	33.9	3.6	16.7	1.6	4.20	28.5	.8	.83	.15	Do.
End of flue near stack.	2.00	15.7	26.8	3.3	15.2	1.6	5.10	21.6	6.0	9.75	.65	Sample taken from copper smelter; collected by condensation on glass tube.
Do	.70	14.2	27.3	3.6	18.3	.5	3.50	22.9	10.7	6.14	.95	Do.
Do	.30	6.1	21.0	.8	10.3	None.	1.00	18.0	19.7	13.52	4.25	Sample taken from lead-smelter roaster flue and from blast-furnace flue near stack.
Do	.90	6.9	24.4	.7	9.4	None.	.30	16.6	24.1	10.26	1.25	Sample taken from lead-smelter blast-furnace flue.
Do	3.30	17.8	29.0	4.20	9.6	.80	1.50	15.8	15.5	6.00	1.90	Sample taken from lead smelter blast furnace.

FORMATION OF SULPHATES.

The particles of ore charge that are thrown over by the action of the furnace gases, especially sulphide-ore particles, usually suffer chemical change. The particles, carried in a gas stream which sooner or later becomes somewhat oxidizing, are changed in part to sulphates, and, as may be seen from the results of analyses, the sulphuric acid content of most of the flue dusts is rather high. The sulphates found in flue dust are: Normal ferrous sulphate, $FeSO_4$; basic ferric sulphate, $Fe_2O_3.2SO_3$: normal copper sulphate, $CuSO_4$; basic copper sulphate, $2CuO.SO_3$; normal zinc sulphate, $ZnSO_4$; basic zinc sulphate, $3ZnO.2SO_3$; normal lead sulphate, $PbSO_4$; and basic lead sulphate, $6PbO.5SO_3$. It has already been stated that the sulphur trioxide content of the furnace gases is largely due to the decomposition of sulphates.

Particles of sulphide minerals, such as pyrite, pyrrhotite, chalcopyrite, and chalcocite, when subjected to high temperature in the presence of oxygen under certain conditions, particularly such as prevail in roasting furnaces, are changed in part to sulphates. It is probable that the sulphates first formed are the normal sulphates, and that with an increased temperature these are in part decomposed, with the formation of basic sulphates and sulphur trioxide. A still further increase in temperature causes the decomposition of the basic sulphates, with the formation of oxides of the metals and a further liberation of sulphur trioxide. This action is particularly in evidence in roasting furnaces. Particles of charge thus changed are carried over as flue dust.

A formation of sulphates also takes place in the flues, where, at high temperature, sulphide particles in the flue dust are subjected to the oxidizing action of the smoke stream. An examination of Table 3 shows the high sulphur trioxide content of all the flue dusts. This sulphur trioxide is divided into that which is soluble in water and that which is not soluble in water. The normal sulphates of copper, iron, and zinc, and free sulphuric acid and free sulphur trioxide are readily soluble in water, whereas the basic sulphates of these metals and the normal and basic sulphates of lead are practically insoluble in water. If a sample of flue dust be treated with water and the resultant water analyzed for sulphur trioxide. the result will be a measure of the amount of soluble sulphates, sulphuric acid, and sulphur trioxide present, and the total sulphur trioxide, less the soluble sulphur trioxide, will give the proportion that is combined as basic sulphates and lead sulphate. Most of the sulphates are hygroscopic; that is, they will absorb water and become hydrated. Some of the normal sulphates have an acid reaction, and flue dust high in sulphates has a corrosive action on vegetation.

EFFECT OF VELOCITY OF SMOKE STREAM ON COMPOSITION OF FLUE DUST.

In some of the older plants of this country the velocity of the smoke stream in the flues was frequently more than 30 feet per second, with the result that the stacks emitted a considerable quantity of true flue dust which was scattered broadcast in the vicinity of the plant, doing damage. The more modern plants do not, however, have such high velocities in their flues and little true dust is discharged from their stacks. The chemical composition of flue dust is, of course, dependent upon the nature of the ore charge smelted; that from a copper smelter will differ from that of a lead smelter. The general nature of flue dust, particularly in reference to sulphate content, is very similar at all plants. Formerly, with the high velocities of gases in dust chambers and flues, the losses from dust were considerable. At the present time the large plants make a serious effort to reduce these dust losses. Examination of Table 2 will show that the copper content of the flue-dust samples is considerable.

LOSSES FROM FLUE DUST.

Even with only small quantities of dust in the gases, as they are discharged from the stack, the losses are serious. Thus, at Great Falls, Mont., the stack discharges daily 931,204,320 cubic feet of gas (standard conditions), which carries 50,690 pounds of dust and fume. The Anaconda, Mont., plant discharges daily 1,341,000,000 cubic feet of gas (standard conditions), which carries 153,554 pounds of dust and fume. Even with only 1.5 to 2.5 per cent of copper in this dust, the loss for the year will bulk large.

IMPORTANCE OF PROPER DESIGN OF DUST CHAMBER.

The importance of so designing the dust chamber and flue system as to minimize this dust loss is therefore evident. Recently experimentation and practical experience have proven that it is possible, by adopting proper means, to cause practically all of the true flue dust to settle from the smoke stream. If the smoke stream be conducted through dust chambers of correct cross section and length, the dust will settle satisfactorily. Although formerly it was the practice to maintain a velocity of gas in dust chambers and flues as high as 30 to 40 feet per second, the speed now commonly accepted as proper for the smoke stream in dust chambers is 2½ feet per second in plain chambers and 5 feet per second in chambers hung with wire baffles (Roesing system). The length of dust chambers must be sufficient to give the dust an opportunity to settle. With a speed of 2½ feet per second all but the very finest dust settles in 50 seconds in plain chambers. Hence, if the cross sections of the dust chamber be proportioned to the volume of the gases, so as to give a speed of 2½ feet per second, the length of the dust chamber should be made

125 to 150 feet. If wire baffles are used the speed may be doubled and hence the cross section diminished by one-half of the above. These figures represent practice at two great copper plants. The speed of the gas stream in flues may be greater than this. At the Great Falls plant, mentioned above, the velocities were as follows: Blast-furnace flue, 17.3 feet per second; roasting-furnace flue, 17.5 feet per second; main dust chamber, 5 feet per second; connecting flue to chimney, 21 feet per second; chimney, 10 feet per second. At the Anaconda plant the velocity in the main flue, at a point 30 feet below the stack, was 21.43 feet per second. In general, the practice is to build flues of such cross section as not to exceed a speed of about 20 feet per second and at some convenient place to interpose in the flue a dust chamber of such cross section as to diminish the velocity of gases to about 5 feet per second, and to so design the entrance or exit of the flues into or from the dust chamber that the gas stream is forced to expand and uniformly reduce its velocity in its passage through the chamber.

LOSSES FROM FINE DUST.

Only a part of the true fume can be recovered by a reduction of the velocity of the gas stream, even with proper cooling so as to precipitate the fume. The reluctance of fume particles to settle like true dust particles is discussed more in detail elsewhere. Losses in fine dust and fume through the stack are usually expressed in terms of grains per cubic foot of smoke discharged. One pound avoirdupois contains 7,000 grains. The fine dust and fume discharged with the smoke stream is generally referred to as the solids in the smoke stream. The total quantity of solids discharged by the gas stream at Great Falls and Anaconda has already been mentioned. Expressed in grains the figures are as follows: Anaconda, 0.798 grain per cubic foot; Great Falls, 0.378 grain per cubic foot. It is necessary to state that the methods used at Anaconda and Great Falls to determine this data are radically different and that perhaps the figures are not strictly comparable. At the time the Balaklala plant at Coram, Cal., was in operation the smoke stream discharged from the stack contained 0.638 grain per cubic foot. During trials on a large scale of the electrical precipitation process, this was reduced to 0.149 grain per cubic foot.

ARSENIOUS OXIDE IN FLUE DUST.

The fine flue dust and fume that settles in the flues near the stack frequently contains a considerable proportion of arsenious oxide fume. The oxide is especially likely to occur at smelters that treat ores containing appreciable arsenic, such as the Butte (Mont.) ores. The flue dust is the source of most of the arsenious oxide or white arsenic produced in the country. The copper-smelting plants at Anaconda and at Great Falls, Mont., each produce some arsenious oxide. Arsenious oxide is also produced from fume at the smelter at Midvale, Utah, and at the Globe plant at Denver, Colo. The arsenic-bearing flue dust in copper smelters and the fume from the bag houses of lead smelters are heated in specially constructed reverberatory furnaces to volatilize the arsenious oxide, which then again sublimes in the flues. This crude arsenic product is gathered and again subjected to heating in a refining furnace, and the volatilized arsenious oxide once more sublimes in flues, yielding the refined arsenious oxide, or white arsenic, of commerce. Only part of the arsenic in the ores smelted is recovered from the flues of copper smelters. In lead smelting practically all of the arsenic is caught with the fume in the bag houses. The present demand for arsenious oxide is not great enough to warrant copper-smelting plants to seek a full recovery of the arsenic in their ores.

HANDLING OF FLUE DUST.

The flue dust that is recovered from the dust chambers and flue system of a plant must of necessity be again treated. The economic treatment of this fine material, which represents usually 2 to 10 per cent of the total material smelted, is often a serious problem. It is to be noted that this material has already passed through a number of costly operations and stands charged with costs for labor and power. The problem of a successful and economic handling of fine flue dust and other fine material is general in metallurgy, to be found in the metallurgy of iron as well as in that of copper, lead, gold, and silver. In large copper-smelting plants, reverberatory smelting furnaces afford a means of successfully resmelting flue dust in conjunction with other fine material, but in lead and iron smelting, it is necessary to charge the dust back into the blast furnace, where, of course, if it be returned in its original condition, it will again be largely blown into the flues. Within the past few years, sintering machines have been successfully applied to fine material and flue dust. These machines operate so as to sinter or incipiently fuse the small particles of the flue dust and fines into an agglomerated porous mass, which can be broken readily into pieces suitable for blast-furnace smelting. Also, flue dust may be briquetted for smelting.

METALLURGICAL FUME.

COMPOSITION AND CLASSIFICATION OF FUME.

Fume may be defined as a mixture of very fine particles of elements and metallic and nonmetallic compounds either sublimed or condensed from the vapor state. In practice, it has mixed with it comparatively small proportions of fine flue dust. Moreover, fume may consist of very small solid particles and of very small liquid particles, the latter like a mist or fog. The composition of metallurgical fume varies within wide limits, dependent upon the method of smelting employed. Broadly speaking, it can be divided into two classes—first, oxidized fume, which contains the metallic elements in the form of oxides or highly oxidized compounds, and, second, nonoxidized or raw fume, which contains the metallic elements in the form of compounds not associated with oxygen. The first class is typically represented by fume from copper blast furnaces and converters, and the second class by lead blast-furnace fume.

ANALYSES OF TYPICAL FUME SAMPLES.

In Table 4, following, are presented the results of analyses of fume from various kinds of plants in different parts of the United States.

TABLE 4.—*Results of analyses of fume from various plants.*

Constituent.	Anaconda, Mont., solids discharged from stack.	Western copper smelter, solids discharged from stack.	Mammoth, Cal., blast-furnace bag-house material.	Murray, Utah, plant.		Omaha, Nebr., plant.		Fume from a flue receiving gases from mechanical roasters and sintering machines in a lead smelting plant.[a]
				Blast-furnace bag-house material, raw.	Blast-furnace bag-house material, sintered.	Fume from converter bag-house.	Raw fume from blast-furnace bag-house.	
	1	2	3	4	5	6	7	8
	Oz. p. ton.	*Oz. p. ton.*	*Oz. p. ton.*	*Oz. p. ton.*	*Oz. p. ton.*	*Oz. p. ton.*	*Oz. p. ton.*	*Oz. p. ton.*
Silver	5.07		6.70	2.62	2.40	2.80	10.00	
Gold			.01	.0149	.014			
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Silica	4.19	2.30	1.48	2.09	2.50			
Alumina	3.14	[b] 7.08	1.68					
Ferric oxide	2.78	[c] 7.08	4.22					
Zinc oxide	11.84	3.31	40.57					
Antimonious oxide	1.17	1.47	.54					
Lead oxide	11.63	.49	9.33					
Bismuth oxide	1.15	.81	.26					
Cupric oxide	1.05		.90					
Arsenious oxide	34.34	38.10	10.02					
Tellurous oxide	.35							
Sulphur	[d] 1.88		[d] .68	[e] 5.20	[e] 4.20		[e] 5.40	[e] 25.50
Sulphur trioxide	[f] 19.65 [g] 3.65	[h] 16.67	[e] 23.84			[f] 21.63		
Lime	.50	.18	.91					
Magnesia	.69		.10					
Soda	.49		.88					
Potassa	.42		.38					
Carbon	.80						Considerable.	10.03
Copper		.70		.058	.05		Trace.	.30
Sulphuric acid		22.23						
Water		[i] 4.45	[j] 3.80					9.70
Phosphorus pentoxide			.15					
Selenium			.05			.24		
Oxygen			.34					16.4
Iron				5.10	5.20			5.03
Zinc				3.20	4.20	1.90	3.00	1.50
Arsenic				36.60	33.50	2.00	14.20	2.67
Lead				28.42	27.30	66.00	52.50	22.50
Antimony						.20		.87
Tellurium						.20	Trace.	
Insoluble constituents								5.50

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[a] From other data as regards the manner in which sulphur was present the probable actual composition of this fume was as follows: Insoluble constituents, 5.5 per cent; zinc sulphide, 0.68 per cent; iron sulphide, 3.93 per cent; elemental sulphur, 13.82 per cent; copper sulphate, 0.75 per cent; ferrous sulphate, 6.90 per cent; zinc sulphate, 2.60 per cent; lead sulphate, 31.24 per cent; lead sulphide, 1.34 per cent; sulphuric acid, 8.98 per cent; arsenic sulphide (As_2S_2), 3.81 per cent; antimony sulphide (Sb_2S_3), 1.22 per cent; water, 9.70 per cent; remainder, carbon and some oxygen in basic sulphates. The first three constituents were probably present as fine "flue dust." Silver, 5.40 ounces per ton; gold, 0.015 ounce per ton.

[b] Includes ferric oxide. [d] Free and as sulphide. [f] Combined. [h] As sulphate. [j] At 250° C.

[c] Includes alumina. [e] Total. [g] Free. [i] At 100° C.

In the table, analyses 1, 2, 3, and 6 represent the first class and 4 and 7 the second class. In the copper blast furnace and converter the atmosphere is usually oxidizing and the oxide compounds of the volatile metals are naturally produced. On the other hand, in the lead blast furnace the conditions are essentially reducing, and volatile nonoxidized compounds are produced. The fume from lead blast furnaces may readily be ignited and will smolder and burn, the unoxidized compounds becoming converted into oxidized compounds. In Table 4, analysis 4 represents raw or unburned fume and analysis 5 the same fume burned and sintered. The constituents and figures given in Table 4 do not necessarily represent the true composition of the fume. Thus arsenic is given in the table both in the form of elemental arsenic and of arsenious oxide. Sulphur is given as free sulphur, as combined in the form of sulphide, as combined in the form of sulphuric acid, as free sulphur trioxide, and as sulphur trioxide combined with a base. The manner in which the substances are stated depends largely on the chemist that makes the analysis. No attempt has been made in the table (except in analysis 1 of fume from Anaconda) to combine the constituents into the compounds such as they actually exist in the fume.

SUBSTANCES FOUND IN FUME.

The following substances may be found in the type of fume under discussion: Metallic gold and metallic silver; quartz and silicates of potassa and soda; silicates of alumina, lime, and ferrous oxide, probably carried into the fume as fine-blown slag and ore particles; zinc oxide; normal zinc sulphate; basic zinc sulphate; cadmium oxide; antimonious oxide; antimonious sulphide; lead oxide; lead sulphide; lead sulphate; cupric oxide; cuprous oxide; elemental arsenic; arsenious sulphide; arsenious oxide; elemental tellurium; tellurous oxide; elemental sulphur; sulphur trioxide; free sulphuric acid; elemental selenium; selenium oxide; thallium oxide; soda and potassa.

Which of the above compounds occur in fume depends upon the condition under which the fume is produced. Thus, in copper smelting, any lead in the ore is probably vaporized as lead oxide and is found in the fume as such or in the form of lead sulphate if considerable sulphuric acid be present in the smoke stream. Zinc under similar conditions is in part vaporized as zinc oxide from the combustion of zinc sulphide mineral and is found as such in the fume or as zinc sulphate. Usually, the bases, zinc and lead oxide, neutralize most of the sulphuric acid which is formed in the fume in the manner previously described. The oxides of zinc and lead are carried as extremely minute solid particles in the smoke stream after a certain degree of cooling and probably act as centers of condensation for the sulphuric acid vapor, thus causing the formation of the sulphates of zinc and lead.

FACTORS DETERMINING STATE OF OCCURRENCE OF METALLIC PARTICLES IN FUME.

Whether a metallic compound exists in the smoke stream as a vapor or is sublimed or condensed depends, of course, upon the temperature and the saturation vapor tension of the compound for that temperature, as is more definitely explained for the compound arsenious oxide, one of the most important constituents of fume. Figure 1 gives the vapor-tension curve of this compound, plotted on the basis of amount of arsenious oxide per cubic foot of smoke stream, and the temperature. It will be noted that at a temperature of 833° F. a cubic foot of the smoke stream can hold 0.325 pound of arsenious oxide in the vapor condition. At 700° F. a cubic foot can hold only 0.05 pound. Therefore, if a cubic foot of smoke saturated with oxide be cooled from 833° to 700° F. 0.275 pound of arsenious oxide will be condensed as a fume. If the smoke be not saturated with arsenious oxide vapor for a given temperature, in other words, if less arsenious oxide than the smoke can possibly hold be present, the smoke will have to be cooled to a temperature such that the proportion of arsenious oxide present represents saturation, before any sublimation of fume takes place. From the curve it may be determined that when the smoke has been cooled to 250° F. a trace only of the arsenious oxide is in the vapor form, practically all of the oxide has sublimed and is in the form of very fine solid particles.[a]

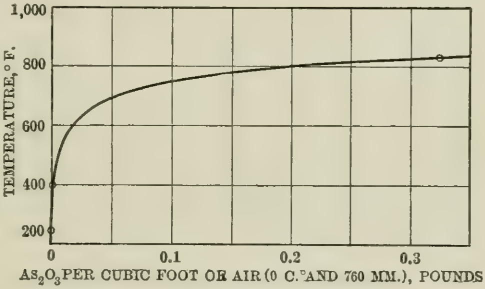

FIGURE 1.—Arsenic trioxide saturation curve.

What has been stated for arsenious oxides applies in a general way to all of the compounds in the fume, except that the saturation pressures and temperatures vary for each and every compound. The temperatures at which sublimation or condensation is practically complete for the compounds named as common in fume are higher than that for arsenious oxide. Hence no metallic compounds as vapor pass up the stack with the smoke stream, but such as are lost are in the form of sublimed or condensed particles. Evidently the cooling of the smoke stream, in order to permit sublimation and condensation, is very important. The cooling is accomplished in some plants by the admission of cold air to the smoke stream, and in others, as, for instance, in certain lead-smelting plants, by passing the gases through a long flue system, part of which consists of sheet-iron or steel flues, the cooling effect of which on account of their high heat conductivity is pronounced.

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[a] For a discussion of the vapor pressure of arsenic trioxide, see Welch, H. V., and Duschak, L. H., The vapor pressure of arsenic trioxide: Tech. Paper 81, Bureau of Mines.

As already stated, fume particles are in an extremely minute state of division and do not settle from the gas stream by gravity as ordinary flue-dust particles do. Even though the gas stream be cooled so that complete sublimation or condensation can take place and the velocity of the stream be reduced to a low rate, little settling of fume occurs. In fact, surfaces somewhat heated, particularly if they be moist, seem to have a decidedly repellant action on the fume particles. This peculiar action of fine particles near heated surfaces is well known. It is probably due to their bombardment by gas molecules repelled from the heated surfaces. A similar force operates the well-known device known as Crooke's radiometer. The behavior of minute particles in a fluid, gas, or liquid has been investigated by Stokes. With a given viscosity of the fluid, particles of a certain minuteness do not settle by gravity, the frictional forces being sufficient to keep the particles in suspension. In the settlement of very fine colloid particles (slimes) in liquids, similar conditions prevail and settlement can not be effected. It would seem that the laws governing these very fine solid particles in fluids are still little known and afford an interesting field for research.

AN UNSATISFACTORY METHOD OF REMOVING FUME.

One of the methods that has been advocated for many years to remove fume from smelter smoke is the spraying of the gas stream with water, accomplished by forcing the gas stream to rise against water sprays in towers or by adding to the gas stream, while still hot, large quantities of steam, which later condenses, or by passing the smoke stream through centrifugal gas washers, such as the Theisen washer, with a view to thus removing the fume. The method removes flue dust with fair success, but is not satisfactory for fume, so that the statement may be safely made that the application of water to the smoke stream in various ways for the removal of fume holds out little promise. Fume can be readily removed by filtering the smoke stream through fabrics or by electrically precipitating the particles. These methods for the removal of fume from the smoke stream are discussed in following pages.

DAMAGE CAUSED BY FUME.

The escape of fume from the stacks causes not only a loss of valuable material under certain conditions, but is also occasionally the cause of considerable damage. Damage by smelter smoke, as already outlined, may be caused by two constituents of the smoke, first, the sulphur dioxide, and, second, the fume and flue dust. The damage by the solids is done when they are of a poisonous nature, as for instance, arsenious oxide and lead compounds, or when they consist of acid sulphates or particles to which adhere sulphur trioxide and sulphuric acid. When the smoke stream contains considerable arsenious oxide, vegetation in the vicinity of the smelters may become contaminated with this poison, under certain climatic conditions, particularly when little rain falls, so that the oxide concentrates on plants and leads to the poisoning of stock. High stacks, which tend to scatter this poisonous fume over large areas and thus prevent any concentration of the arsenious oxide in sufficient quantity to be really harmful, usually solve the difficulty experienced from this source.

A number of plants recover considerable arsenious oxide as a by-product, and could recover a still larger percentage of that in the ore if the market warranted such recovery. However, the demand for this substance is somewhat limited, so that some of it is permitted to escape. The damage to country surrounding smelters from the solid constituents of the smelter smoke is now not as great as formerly, since the installation of adequate flue-dust settling facilities and high stacks. Formerly, with low stacks and inadequate settling facilities and high velocities of smoke stream in flues, the damage due to solids was probably considerable. The corrosive effect on vegetation of flue-dust particles and fume charged with sulphuric acid, metallic sulphates, and sulphur trioxide is very pronounced, and when much of this material is discharged from stacks, as will happen in connection with poorly designed flue systems, the damage to vegetation may be serious. It is to be noted here that damage by sulphur dioxide gas is not included in this discussion and is something entirely apart.

It is an interesting fact that when the discharge from smelter stacks is made invisible, or nearly so, by the removal of fume, either by filtering the discharge through bags or by electrical precipitation, little complaint is heard from the surrounding country, even when the fume itself is practically harmless, and when real damage may still be done by the sulphur dioxide gas, which, of course, is invisible. The writer knows of one plant that discharges a nonvisible smoke stream containing considerable sulphur dioxide which occasionally in damp weather causes minor damage. This damage is not particularly noticeable, but at times when a bag house is not in working order for a brief period and the smoke becomes visible, owing to unfiltered fume, complaints arise about damage done, although the occurrence of any real damage is questionable. From a psychological standpoint it seems to be desirable to make the smoke stream invisible by the complete removal of fume.

RECOVERY OF FLUE DUST AND FUME AND METHODS PROPOSED FOR RENDERING SMOKE HARMLESS.

RECOVERY OF FLUE DUST.

Within the past five or six years the realization has come to smelter managers that in many plants a considerable loss of valuable material may take place in the fine flue dust discharged with the smoke stream. This question has already been discussed in some detail in the preceding pages, and the intention here is to outline the actual methods adopted to overcome the loss. Officials of two large copper-smelting plants in this country have investigated this question thoroughly and have acted on their investigations by constructing suitable devices to overcome losses. One is the Anaconda company's smelter at Great Falls, Mont., and the other is the smelting plant of the Copper Queen mine, in Arizona.

SAVING AT ONE PLANT USING IMPROVED FLUE SYSTEM.

It was demonstrated at the Great Falls plant that with the old flue system in use there was a daily loss in the dust of 3,775 pounds of copper, 106 ounces of silver, and 0.71 ounce of gold. By using the new flue system, which makes adequate provision for dust recovery, the losses have been reduced to 347 pounds of copper, 28.5 ounces of silver, and 0.2 ounce of gold. The copper loss amounts to 0.19 per cent of the copper charged into the furnaces. The saving thus effected is $372.18 a day, or $130,263 a year. The cost of the new flue system was $1,100,000, so that the saving made much more than pays the interest charges on the investment.

LOSSES FROM FLUE DUST CONSIDERABLE.

At the plant of the Copper Queen mine it was discovered that there was considerable loss through dust passing out the stack. The daily copper loss due to this cause was estimated to be about 6,000 to 18,000 pounds, dependent on the number of furnaces in operation. Reference to Table 2, giving flue-dust composition at some Utah plants, will show that certain of these dusts were taken at the base of the chimney and that their silica content is high. This would indicate a large percentage of true flue dust in the smoke stream, and, of course, a considerable discharge of dust into the atmosphere.

EFFECT OF VELOCITY OF SMOKE STREAM ON DUST DISCHARGE.

There is no question but that some plants in this country were formerly, and are even at the present time, suffering considerable loss from fine dust being discharged with the smoke stream. The work at the Great Falls and the Copper Queen plants has shown conclusively that dust losses may be largely avoided by a reduction in the velocity of the gas stream to about 5 feet per second. The reduction is accomplished by passing the smoke stream into large dust chambers hung with a myriad of wires in such a way that there is no direct channel through the dust chamber, there being at least 10 obstructions to any passage. The use of wire baffles for the purpose of settling out dust from smoke is known as the Roesing system.

Formerly it was accepted as a fact that the passing of the smoke stream through a long system of flues of such cross section that the velocity did not exceed 20 to 30 feet per second would cause the dust to settle. It was considered that length was essential. In the more modern construction it is found that if dust is to be settled the velocity must be reduced to not more than 2½ feet per second in clear chambers or to 5 feet per second in chambers hung with wires.

DESCRIPTION OF PROPERLY CONSTRUCTED FLUE SYSTEM.

A modern flue system, therefore, may be considered to consist of (1) the individual flues leading from the different furnaces and of such cross section that the gas velocity shall not exceed 20 to 25 feet per second, the flues discharging in a proper manner into (2) a large chamber known as the dust chamber 250 to 350 feet long and of such cross section as to reduce the gas velocity to 2½ or 5 feet per second, dependent upon whether wire baffles are used, and (3) a flue connecting the dust chamber with the chimney and of such cross section that the gases have a velocity not exceeding 20 or 25 feet per second, and (4) a chimney of sufficient cross section to carry the gas stream at this velocity and of sufficient height to give ample natural draft at the furnaces.

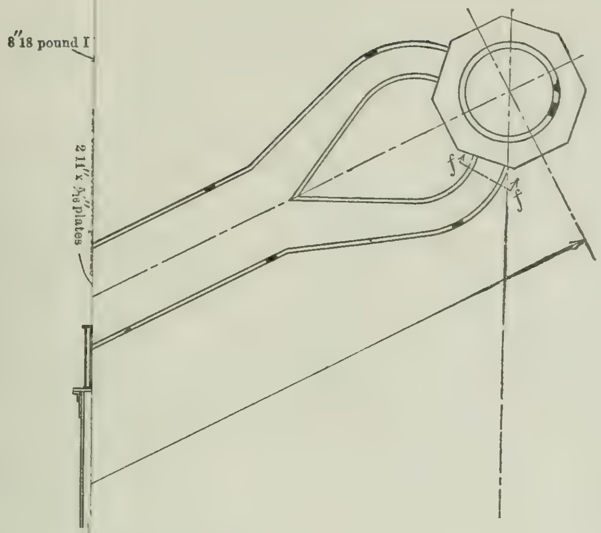
FLUE SYSTEM AT COPPER-SMELTING PLANT AT GREAT FALLS, MONT.

In Plate I is shown the new flue system at Great Falls. It consists of a cross-take flue that discharges into the dust chamber, which connects to the chimney by means of a long connecting flue. Into the cross take and the dust chamber discharge the individual flues from the blast furnaces, reverberatory furnaces, roasting furnaces, and converters. The arrangement of these individual flues is temporary only. They will discharge into the main system somewhat differently after the furnaces have been reconstructed. But the system, from the cross-take flue on, may be considered as a typical modern flue system.

The most interesting part of this is the dust chamber, which is a rectangular chamber 367 feet long, 177 feet wide, and 21 feet high from the top of the hoppers to the roof. It is constructed of brick and steel in the manner shown in Plate II, which depicts a transverse section and a longitudinal section. These views represent sections near the upper end of the chamber, where it joins the connecting flue, in order to show the special features of construction, such as the wire-shaking arrangements *z* and the cold-air pipes *q*. The wire-shaking arrangements provide for the shaking of the wires from the outside of the dust chamber to dislodge dust that has accumulated on the wires. The air pipes *q*, which enter the dust chamber from the top and from the bottom, admit cold air in order to decrease the temperature of the smoke stream and cause the sublimation of arsenious oxide, etc. The dust chamber is set on a large number of steel columns, and the bottom of the chamber is formed by a great number of hoppers (Pl. III, A), from which the collected flue dust may be discharged into cars. Plate IV shows the hopper plan of the bottom of the dust chamber. In all there are 1,042 hoppers. The chamber is divided longitudinally by a brick wall, shown in Plate II and as a heavy line in Plate IV.

USE OF STEEL WIRES.

The area within the dotted lines (Pl. IV) is hung with steel wires, spaced 2.3 inches, center to center, there being a total of about 1,200,000 wires, each of which weighs about 1 pound. The wires are hung in two groups, with a clear space of 47 feet between the two groups near the middle of the chamber. Plate IV indicates that a clear space is left at the inlet end, affording an unobstructed passage for the gases to distribute themselves equally over the full width of the chamber. The total average length of the chamber filled with wires is approximately 317 feet. There are two sizes of wire used in the first group. For a distance of about 51 feet from the inlet end wires 16 feet long and 0.162 inch in diameter are used, the rest are 20 feet long and 0.135 inch in diameter. The second division is hung with wires 20 feet long and 0.135 inch in diameter. At the upper end of the first division of wires there are 22 pipes for the admission of air in case it should be desirable to lower the temperature of the gases. An interior view of the dust chamber showing these air pipes, the wires, and the top of the hoppers is shown in Plate III, *B*. The wires are suspended from crimped iron screen cloth of 1.625-inch mesh stretched along the bottom of the roof purlins. Flat bars, 2½ inches by $\frac{5}{16}$ inch, bolted to the purlins hold the screen in place. The baffle wires are provided with a hook in the form of a shepherd's crook on one end and are suspended from alternate intersecting points on the screen. The wires are shaken for a period of about 30 minutes at intervals of 60 to 90 days, as may be required.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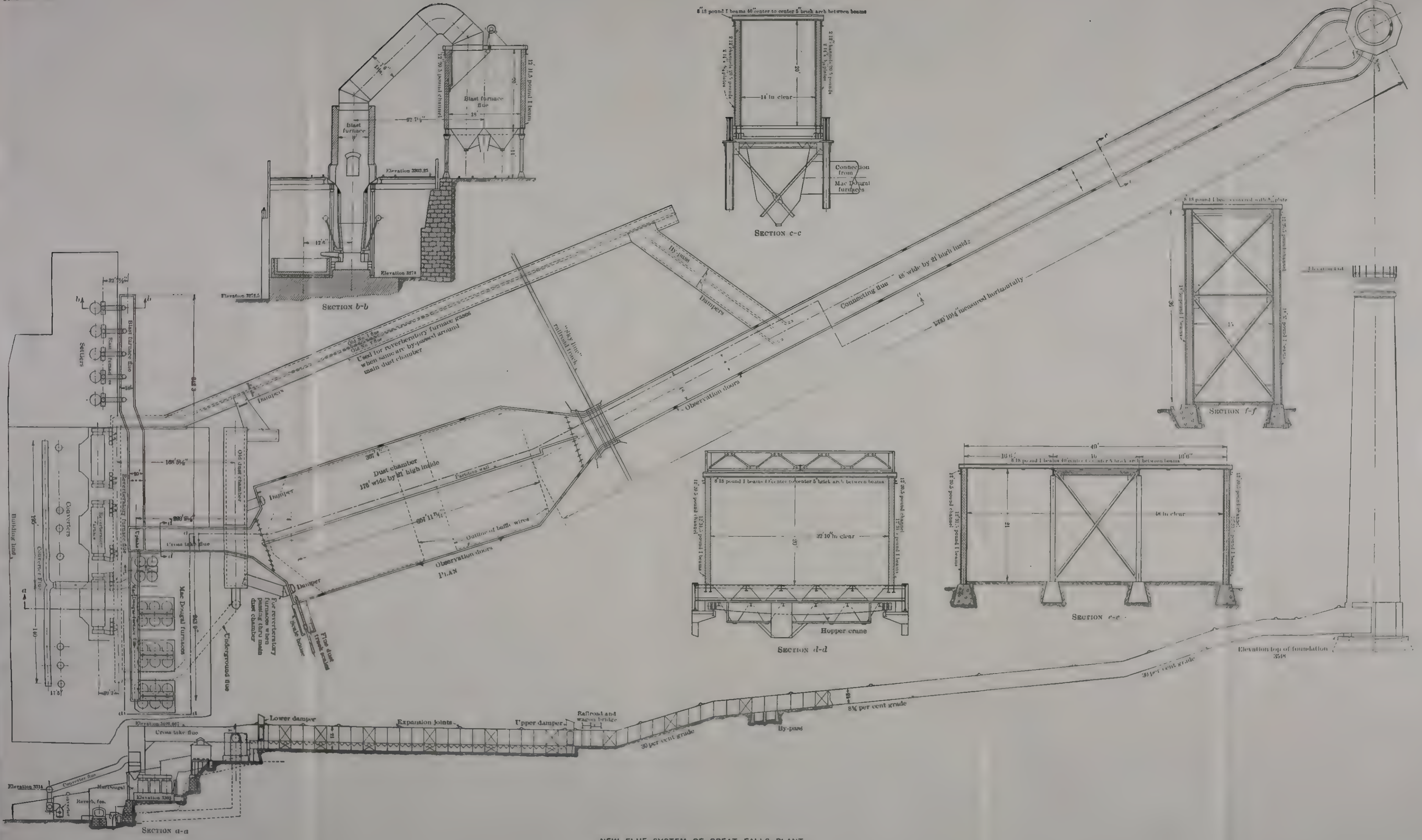


NEW FLUE SYSTEM OF GREAT FALLS PLANT.

USE OF BUTTERFLY DAMPERS.

At one end of the chamber a line of butterfly dampers (x, Pl. II) is provided, so that either side or the whole of the chamber may be closed to the passage of gases. The dampers are made of heavy cast-iron plates which are carried by a vertical shaft. The step bearing at the bottom is below the floor plate, where it is free from dust and can be oiled and inspected. The upper ends of the shafts pass out through the roof of the dust chamber, each one being equipped with a worm and hand wheel for operating the damper. While the shaking device of one side of the chamber is in operation, the dampers on this side are closed and all the gases pass to the opposite side of the longitudinal division wall.

RESULTS OBTAINABLE WITH SYSTEM.

Figures illustrating the results obtainable with the new flue system are as follows:

	Tons.
Amount of copper-bearing material treated during 41 months	1,478,026
Flue dust recovered from:	
Blast-furnace flue	87,020
Roaster-furnace flue	18,741
Uptake and cross-take flue	17,360
Main dust chamber	68,048
Connecting flue	4,000
Total	191,169
Monthly average of flue dust recovered	4,662
Proportion of flue dust recovered, per cent of the material treated	12.93

During the operation of the old flue system there was treated, in 68 months, 2,877,388 tons of copper-bearing material, from which 104,239 tons of flue dust was recovered, or 3.62 per cent. It will be noted that the percentage of flue dust recovered is much greater under the new system with its accompanying improvements than under the old, the difference practically representing what was formerly lost.

In the new system all flues, including the dust chamber, are raised above ground and have hopper discharges, so that it is an easy matter to remove flue dust from the flue system. In many of the older plants at least part of the flues are not provided with this convenience, and the flue dust accumulates in time to such an extent that it is necessary to shut down the plant and clean out the flue system. The continuous accumulation of dust in this kind of flue progressively diminishes the area and necessarily increases the gas velocity, causing increased dust losses. At Great Falls this difficulty is eliminated.

MANNER OF DEPOSITION OF FLUE DUST.

Figure 2 indicates the manner in which flue dust is deposited in the large dust chamber at Great Falls. It will be noted that a great part of the dust is deposited near the entrance of the chamber, over 50 per cent of it being thrown down in the space from the beginning of the chamber to the tenth row of hoppers. The effect of the lack of wires in the center of the chamber is plainly shown by the drop in the quantity of dust deposited.

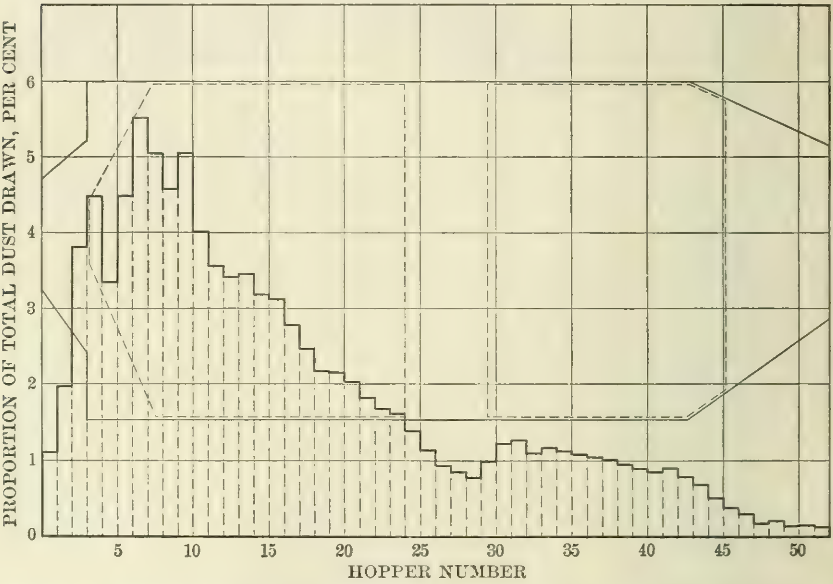
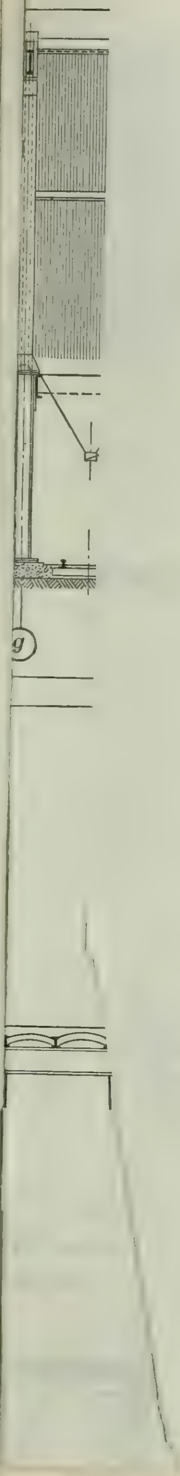


FIGURE 2.—Manner of deposition of flue dust in dust chamber (the dotted lines indicate the space filled with wires).

USE OF WIRE-HUNG DUST CHAMBERS IN OTHER SMELTING PLANTS.

At the Copper Queen smelter in Arizona a number of smaller dust chambers are in use. That connected with the reverberatory furnaces is 1,200 feet in cross section and 132 feet long and contains 30,000 wires That connected with the roasting furnaces is 1,370 feet in cross section, and 114 feet long, and contains 42,000 wires. The proportion of flue dust recovered in the chamber last mentioned is about 6 per cent of the ore roasted.

At the smelting plant at Tooele, Utah, a wire-hung dust chamber was used in connection with the roasting furnaces before an explosion in 1913, and experiments with this system are being conducted at the Tacoma plant of the same company.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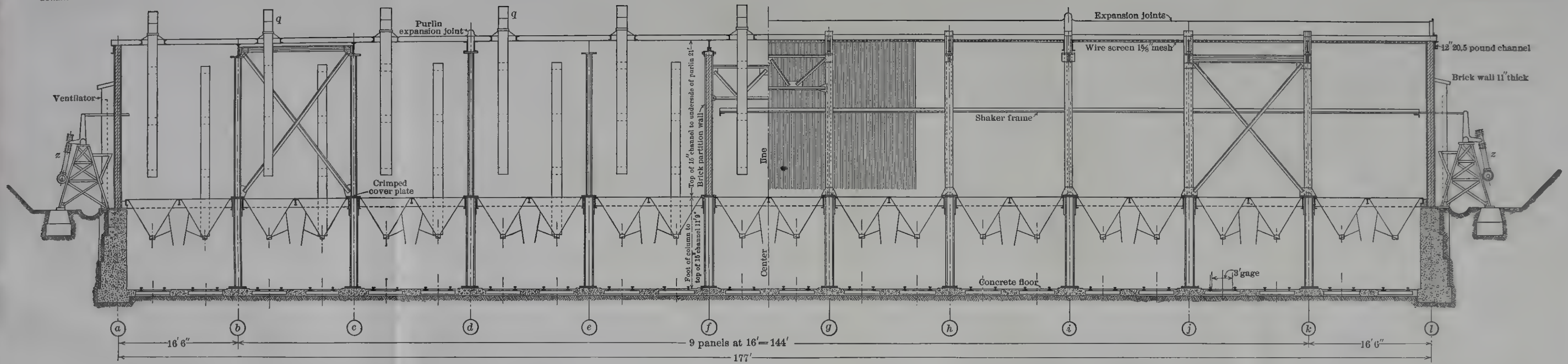
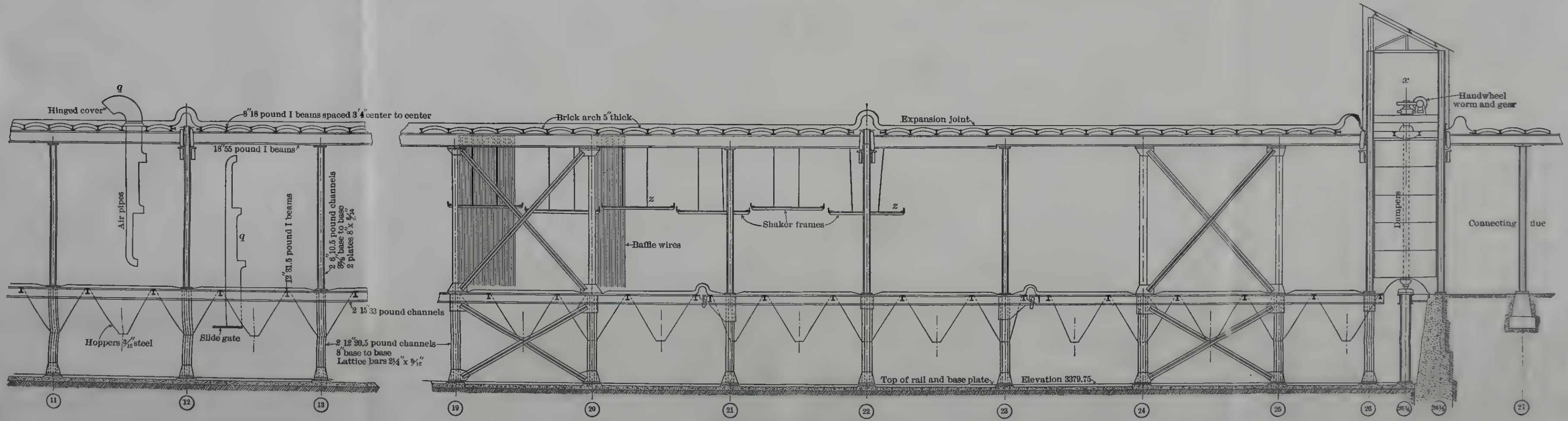


TRANSVERSE SECTION ON LINE 11, WEST HALF

TRANSVERSE SECTION ON LINE 22, EAST HALF



LONGITUDINAL SECTION

MAIN DUST CHAMBER OF GREAT FALLS PLANT.

TREATMENT OF FLUE DUST.

The usual manner of treating flue dust is to charge it as it comes from the flues and dust chambers into the reverberatory smelting furnaces as part of the charge of that furnace. Plants provided with reverberatory furnaces, as most of the copper-smelting plants now are, experience little difficulty in the treatment of flue dust. But when no reverberatory furnaces are at hand, that is, when their use for certain reasons is not warranted, the treatment of the flue dust becomes a serious problem. This problem is encountered in some copper-smelting plants and in all lead-smelting plants. Recently the Dwight-Lloyd sintering machines for the agglomeration of fine sulphide-bearing materials have come into wide use, and at a number of plants they successfully treat mixtures of fine ores and flue dust and prepare them for blast-furnace smelting.

RECOVERY OF ARSENIC.

The material recovered from the flue system under the name of flue dust is not necessarily true flue dust only, but consists usually of a mixture of flue dust and fume. At Anaconda and Great Falls the flue dust that accumulates in the upper part of the flue system contains considerable arsenic. It has been mentioned that at Anaconda and Great Falls this flue dust is re-treated for the recovery of arsenious oxide. By no means can all of the arsenic in flue dust be recovered as arsenious oxide. A certain proportion of this substance is fixed in the flue dust as nonvolatile arsenates. The recovery is usually 50 to 70 per cent. It is stated that at Anaconda the total quantity of arsenious oxide per year in the ores smelted is 15,000 tons. In 1912 this plant produced about 357 tons of arsenious oxide or white arsenic. The total consumption of white arsenic in the United States in 1912 was 6,030 tons, about one-half of which was imported, and the other half is a by-product smelter production. Hence it is useless to seek the complete recovery of the arsenic oxide. Butte ores contain on an average 0.5 to 0.6 per cent of arsenic, expressed as arsenious oxide. This is eliminated in four ways, as follows: (1) In concentrating the ores; (2) as fume carried by the smoke streams discharged by the stack; (3) as arsenious oxide recovered in the arsenic plant; (4) as arsenic eliminated in the blast-furnace and reverberatory slags. The blast-furnace slag at Anaconda carries about 0.24 per cent, and the reverberatory slag about 0.30 per cent arsenic, expressed as arsenious oxide. Probably about 20 per cent of the arsenic in the ores is eliminated in the slag.

USE OF BAG HOUSES IN LEAD-SMELTING PLANTS.

Many lead-smelting plants are provided with a bag house for the recovery of fume and fine flue dust, so that the importance of the proper construction of the dust chamber for the recovery of flue dust is perhaps not so apparent, as fine dust will be readily caught in the bag house. However, a number of lead-smelting plants in this country are not provided with bag houses, and others having bag houses discharge the gases from the roasting furnaces and pots and sintering machines directly into the atmosphere. Hence nearly all lead-smelting plants will profit by installing flue systems of modern design.

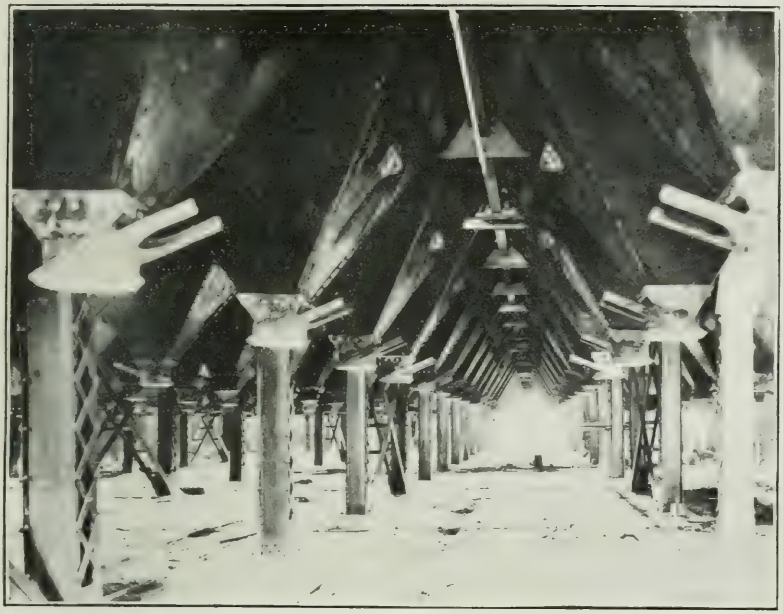
RECOVERY OF FUME.

The nature of fume has been fully described. There are at present two methods employed for the recovery of fume—filtering the smoke stream through woolen or cotton bags and electrically precipitating it by the electrical precipitation process. The first has a rather wide application; the second is just beginning to be used but gives great promise. In general it may be stated that fume will be removed from smelter smoke for two reasons: First, because the fume is valuable and its recovery is profitable, as in a number of instances in lead smelting; and, second, to remove noxious material, such as lead compounds, arsenious oxide, and sulphuric acid, from the smoke stream and to prevent its discharge into the atmosphere, where it will do damage.

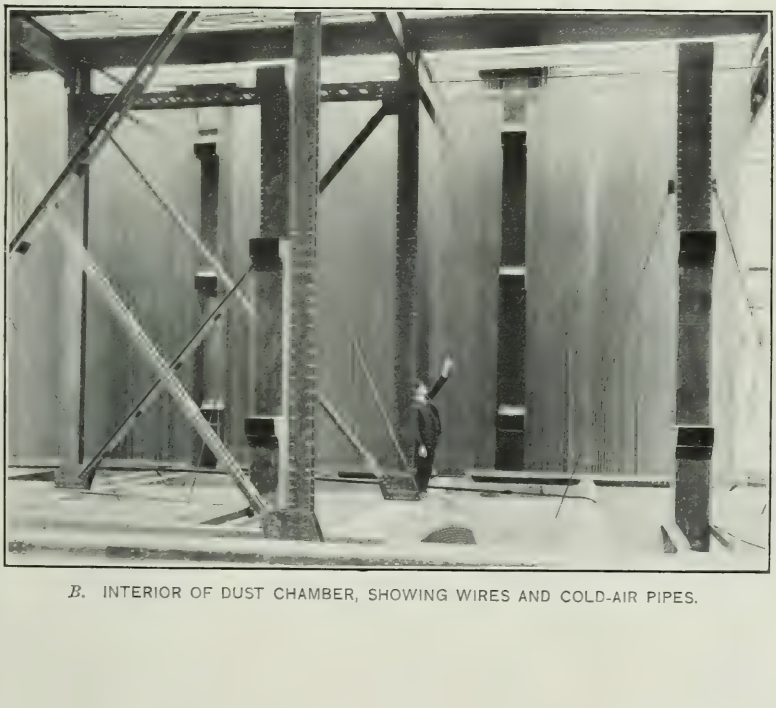
NECESSITY OF BAG HOUSES.

As previously stated, an invisible discharge from smelter stacks is desirable from many points of view. Practically all lead-smelting plants in this country, except a number in Colorado, are provided with bag houses. The bag house has also been applied at one copper-smelting plant, that at Kennett, Cal. The maintenance of a bag house is expensive, and its use is profitable only when smelting in the blast furnace with a high percentage of lead on the charge is being done. Hygienic and legal reasons, however, make its use at lead smelters practically imperative. The fume from a copper smelter is usually not as valuable as that of a lead smelter, so that a bag house for its recovery is even less likely to yield a profit. Furthermore, as regards copper smelters, the temperature of the gases is high and their volume is much greater than in lead smelters, so that the technical difficulties of bag-house operations are greatly increased. Hence the bag house is rarely considered as an adjunct to the copper smelter, except in the instance above noted, where its installation was made necessary by court decisions. The bag-house installation at this plant is described in some detail elsewhere in this report.

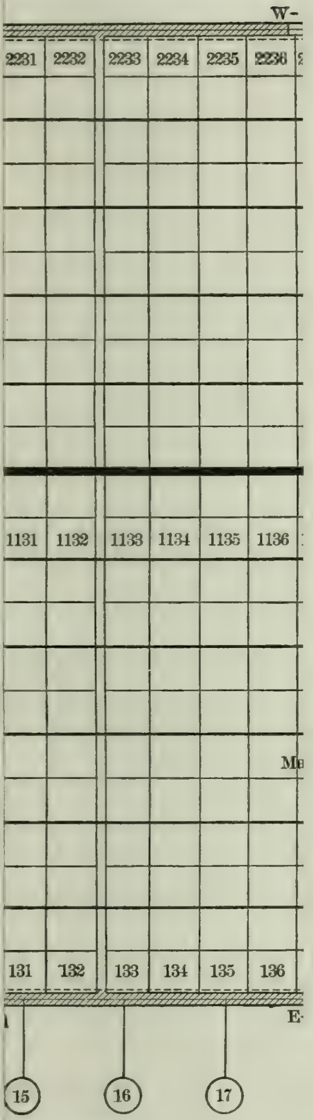
The bag house was first used in the metallurgy of zinc to filter zinc-oxide fume used in paint manufacture. It was next adapted to filtering the fume out of the gases from the lead blast furnace. The endeavor was made to filter the gases from all the furnaces of the lead smelter including roasting furnaces, but it was soon found that



A. HOPPERS UNDER DUST CHAMBER.



B. INTERIOR OF DUST CHAMBER, SHOWING WIRES AND COLD-AIR PIPES.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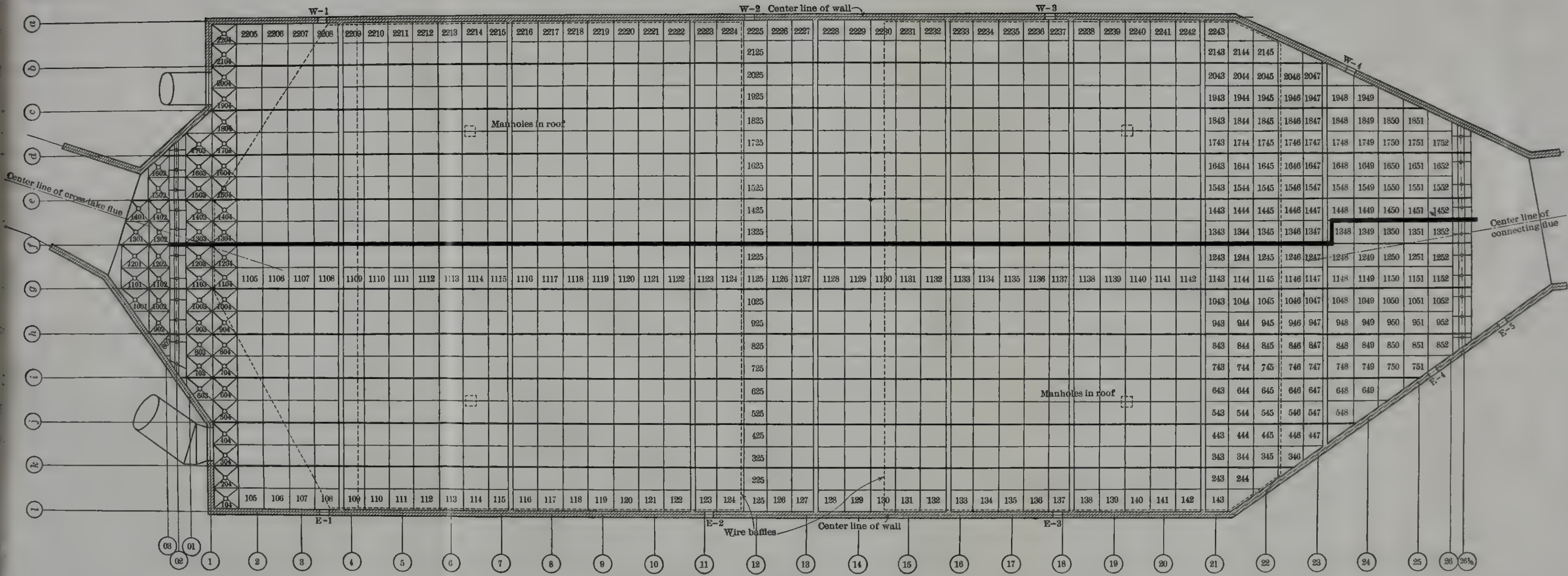

WIRE BAFFLE DUST CHAMBER OF GREAT FALLS PLANT.

the sulphur trioxide and sulphuric acid content of the gases from these furnaces was such as to quickly destroy the fabric of the bags employed, whether they were wool or cotton. Only within the past few years has this difficulty been largely overcome, and at present, with proper precautions, the gases from probably any furnace can be filtered and the fume recovered. In a modern lead-smelting plant there may be employed in the reduction of the ores (1) Huntington & Heberlein pot roasters, (2) Dwight-Lloyd straight-line sintering machines, (3) Wedge multiple-hearth furnaces, (4) Godfrey roasting furnaces, and (5) lead blast furnaces. At some of the plants there are still in operation a number of older style roasting furnaces, such as (6) the hand roasting reverberatory furnace, and (7) the Ropp straight-line mechanical furnace.

DIFFICULTIES WITH DIFFERENT GASES.

Gases from hand roasting furnaces caused most trouble in fume filtering, for they contained not only a relatively large percentage of sulphur trioxide, but also finely divided carbon, and hydrocarbons, products of the coal firing, which in the bag house gave much trouble from spontaneous combustion. The gases from the pot roasters do not present any great difficulty. The gases from the Dwight-Lloyd down-draft sintering machines do not contain a large percentage of sulphur trioxide, but contain considerable free sulphur, which in a number of instances recently has caused rather serious trouble in bag houses attempting to filter the smoke stream from this type of furnace. This sulphur is apt to take fire at some point in the flue and slowly burn to the bag house with disastrous results.

Before fume can be filtered from smoke by means of woolen or cotton fabric the smoke must be cooled below a certain temperature and any sulphuric acid in the smoke must be removed or neutralized. It was found in the metallurgy of zinc that zinc fume could be filtered with impunity under almost any conditions for the reason that zinc oxide would readily combine with sulphuric acid when the fume was properly cooled, as the zinc sulphate thus formed was not harmful to the bags. This principle is applied in the Sprague process, in which zinc oxide fume obtained by roasting zinc sulphide (sphalerite) concentrate on a grate furnace with crushed coal, is permitted to mingle with the smoke stream in the flues before the bag house is reached. As the process is somewhat expensive, part of the zinc may be replaced by finely powdered slaked lime, which is blown into the flues in a suitable manner.

CONSTRUCTION OF BAG HOUSE.

The bag house consists essentially of two chambers, the lower or dust chamber being 12 to 16 feet from floor to ceiling, the upper or bag compartment being 30 to 40 feet in height. The walls and partitions are usually of brick, properly buttressed or held together by tie rods. The dust chamber or smoke cellar is divided by brick partitions into as many compartments (called bays) as there are flues leading to the bag house, thus enabling a part of the bag house to be shut down for cleaning out the collected fume without interfering with the rest of the house. The ceiling of the smoke cellar is made of iron or steel plate and is provided with a number of thimbles or rings projecting into the bag compartment. From the supports near the top of the building cotton or woolen bags are hung, and the lower ends of the bags are tied to the thimbles by means of twine, wire, or hoop bands provided with strap clamps. Each compartment of the bag house has a stack to carry the filtered gases some distance into the air. Fans capable of moving 150,000 to 250,000 cubic feet of gas per minute force the smoke stream with its fume and fine flue dust through a number of large conduits into the smoke cellars and through the bags, the solids being removed so perfectly that the discharge from the stacks is invisible.

NUMBER OF BAGS PROVIDED.

The ordinary bag house is provided with 3,000 to 4,000 bags, each bag being about 18 inches in diameter and 30 to 33 feet long. It is usual to provide 300 to 500 square feet of filtering area for every ton of charge smelted in the blast furnace, or about 3.42 square feet per cubic foot of smoke stream per minute, 2.5 square feet of filtering area being considered the minimum surface per cubic foot of smoke stream per minute that is permissible, although as little as 1.14 square feet has been suggested. At the Midvale smelter in Utah, 25,000 square feet of filtering surface per ton of fume collected per day is provided.

MATERIAL USED IN BAGS.

As a filtering medium, cotton cloth having 42 to 50 threads to the linear inch and weighing 0.4 to 0.7 ounce per square foot was largely used. The objection to this material is that at a temperature of about 200° F. it becomes brittle and breaks, and if used at temperatures of about 100° F. it becomes much weakened by the acid substances in the filtered fume. Woolen material withstands the action of the higher temperature as well as the influence of the corrosive substances in the fume. It will retain its elasticity even when used at temperatures of 250° to 270° F. In modern practice, therefore, it is cheaper in the end to use the more expensive woolen bags than the cotton ones. Recent experience has shown that vegetable fibers should not be used at all; even linen thread for stitching is not satisfactory. At the Murray plant near Salt Lake City, Utah, cotton bags lasted 17 months and cost $2.15 each. These have been replaced by woolen bags which have been in use for over three years and will probably last four years; they cost $4.72 each.

In the lead smelter at Pertusola, Italy, lead fume is recovered by filtering the smoke stream through frames filled with several vertically stretched layers of asbestos thread. These frames are placed in the dust chamber through which the smoke stream is forced by fans. The collected fume is dislodged from the filter frames by releasing the tension on the thread and vibrating the frames. This method is known as the Louis B. Fiechter system. It is evident that this filtering material is proof against acid and high temperature, and may be applicable particularly for copper smelting conditions.

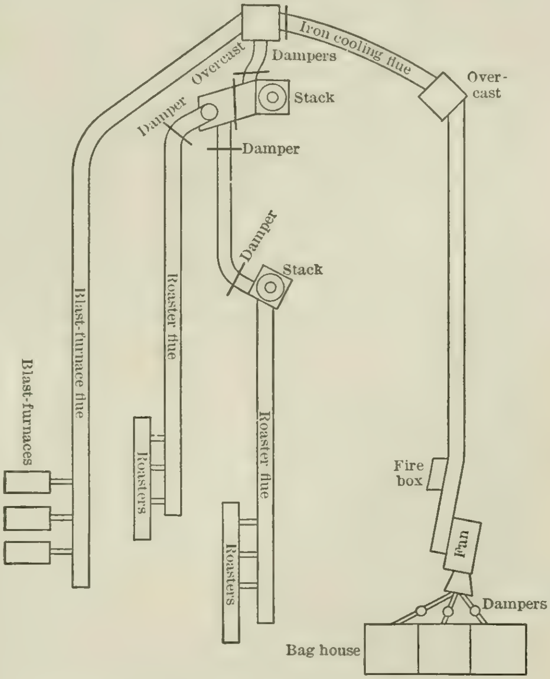

FIGURE 3.—Flue system and bag house arrangement at a western lead smelter.

Experiments in Utah indicated that woven asbestic fabrics are unsuitable to filtering, as they soon become clogged, but the frames with thread in tension are not open to this objection. With woolen bags a wide range of temperature of the smoke stream is permissible. About 150° to 175° F. is safest, but a minimum of 70° F. and a maximum of 270° F. have been used. When the temperature is low there may be trouble from the condensation of water vapor and an increased corrosion from the acid that is formed. The higher temperatures are apt to start spontaneous combustion of the fume or lead to a scorching of the bags. The best practice is to so adjust dampers at the furnaces and in the flues as to maintain a temperature of about 160° F. in the bag house. Under these conditions the material collected in the bag house will be dry and filtration can go on rapidly. At Murray, Utah, the gases entering the bag house have a temperature ranging from about 80° to 125° F. dependent on the season of the year. The placing of limits of temperature on the smoke stream to be filtered makes it necessary to have a flue system under close control. Figure 3 sketches the flue system and bag house arrangement at a western plant. To permit settling of dust and proper cooling of the smoke stream, the usual length of flue between furnaces and bag house is 1,000 to 1,800 feet.

PROPER BAG-SHAKING DEVICE ESSENTIAL.

An important item in bag-house operation is the means adopted for shaking the bags to dislodge the fume caught, so that it may fall into the smoke cellars. The most satisfactory device is the system in which the bags are suspended from short levers attached to a central shaft. The outer end of this shaft projects beyond the wall and is provided with a large lever, so that when this is moved to and fro the tops of the bags are given a similar motion and a wave motion is imparted to the bags as a whole. Bags are shaken usually once every 24 hours. Before the shaking commences, the dampers leading into the bay from the flue are closed.

METHODS OF HANDLING BAG-HOUSE PRODUCTS.

The bag-house fume collected in the smoke cellars usually has a black or dark-gray color (this refers to lead-blast furnace fume), is rather light in weight, and is difficult to handle in its original state. When the fume has accumulated to the depth of about 24 inches, the compartment or bay is closed off from the distributing flue and the cellar doors are opened, as are also the valves connecting with the return flue which leads back to the main flue by means of the fan. Then the fume is ignited by throwing hot coals all over its surface. As the fume burns some fresh fume is evolved from it and is drawn through the return flue by means of the fan and forced again into another part of the bag house. The fume on the floor of the cellar burns slowly, like punk, and gradually sinters to a product resembling soft lava, losing some arsenic and sulphur. The sintering is completed in about five or six days. The sintered fume is removed when cool by laborers using wheelbarrows and shovels. This work, however, is always dangerous and unhealthful, and in the more modern plants efforts are made to handle the fume automatically. At the Murray plant the smoke cellars are somewhat raised and the bottom terminates in a long hopper in which a screw conveyor pushes the fume and dust to the front of the bag house, where it is automatically discharged into cars. The bag house of the Mammoth company at Kennet, Cal., has 20 pyramid-shaped hoppers under the thimble floor. In these hoppers are small circular gates through which the dust is drawn into cars. The dry fume while being drawn off was so annoying to the workmen that the hoppers are now provided with nipples that project into wooden troughs filled with water so that the fume discharges into water, which is drawn into tanks, where the fume settles.

All fume is not combustible, like the fume produced under the reducing conditions obtaining in the lead blast furnace. The fume from copper blast furnaces and from converters is already thoroughly oxidized and on account of its fluffy character gives much more trouble in handling than the lead blast-furnace fume, which can be sintered as described. Lead blast-furnace fume, after sintering, is sent to the arsenic refinery, where it is heated and the arsenic volatilized as arsenious oxide and again sublimed. The residue from this treatment contains considerable lead and some silver and gold and is usually sent back to the blast furnace to be resmelted.

RELATION OF BAG HOUSE TO HEALTH OF WORKMEN.

The labor question in bag-house management is somewhat serious, for the work is dangerous to health. The men employed should be intelligent and have the greatest regard for thorough cleanliness. Heavy clothing, consisting of heavy underwear, socks, overalls, jumper, cap, gloves, and shoes, should be worn. Formerly, rubber coats, gloves, and hats were used, but have now been discarded. A specially designed change house, divided into three parts, should be used. When the men leave their work, they go to the third part, remove their heavy clothing, and hang it where it can be thoroughly aired. They then pass to the washroom and bathe from head to foot, using plenty of soap and hot water. They next go to the locker room where they resume their ordinary clothing. The greatest care is desirable. When eating at the works workmen should always wash their hands thoroughly and be careful not to bring food in contact with their clothing or anything that has been exposed to the fume. With these precautions, men rarely suffer injury from the handling of fume. The same precautions apply to work in the arsenic refineries. Arsenic, aside from the dangers of its ingestion, will produce chronic sores on the skin and mucous membranes. A mixture of ferric hydroxide, lanolin, and some vaseline is a good ointment for the face and other exposed parts and affords considerable protection.

BAG HOUSE AT MURRAY, UTAH.

Figure 4 shows elevations and sections of the bag house at Murray, Utah. The main flue coming from the furnaces is shown at *a; b* represents the fan house, containing an exhaust fan with a capacity of 225,000 cubic feet of gas per minute at a pressure of 1 inch of water. The fan is driven by a 75-horsepower motor capable of making 150 revolutions per minute. Pressure in the distributing flue *c* leading to the bag house is usually about 0.5 to 0.75 inch of water, which represents the resistance of the bags to the passage of gases. The outside dimensions of the bag house are 216.5 by 90.5 feet. The height to roof trusses is 51.5 feet.

The house is built of brick, the outside wall being 21 inches thick for a height of 16 feet, then reduced to 17 inches for 18 feet, and to 13 inches for the remaining height. Forty-eight brick buttresses *d*, projecting 4 feet at the floor line and tapering to about 1 foot at the roof-truss line, are built into the walls to stiffen them. There are 17 buttresses on each side and 7 on each end. The bag house is completely divided into four compartments, or bays, by brick partitions running from the floor line to the apex of the roof. Below

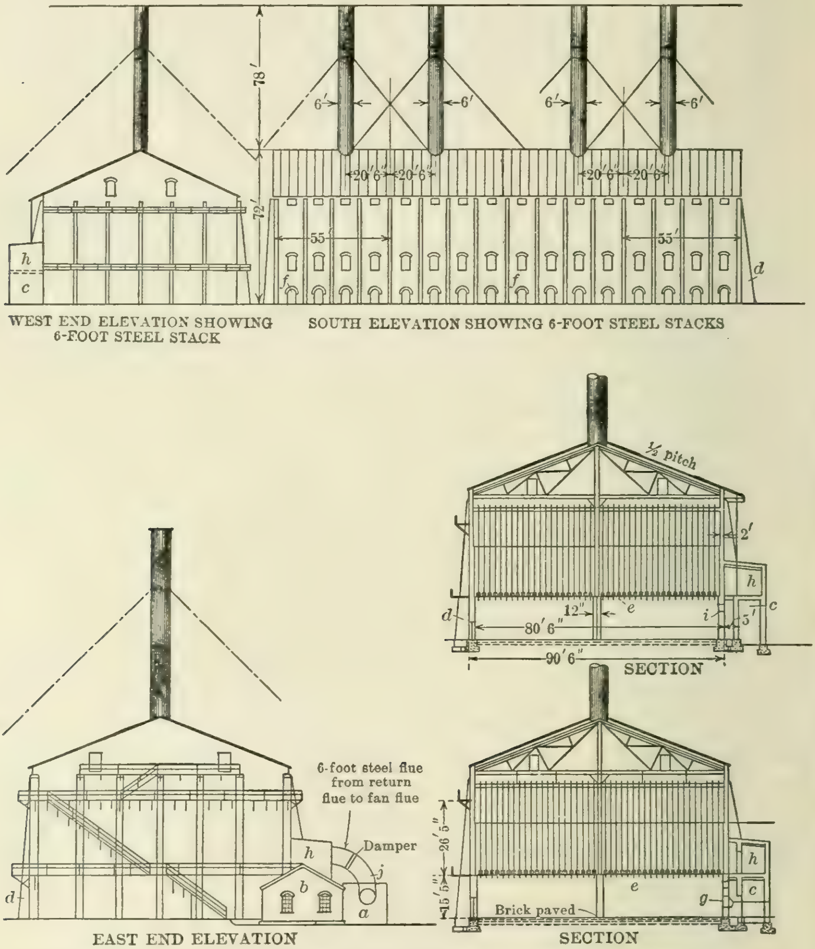

FIGURE 4.—Elevations and sections of bag house of smelter at Murray, Utah.

the thimble floor *e* each compartment is divided into four chambers or smoke cellars by brick partitions. Each cellar is 87 by 12 feet in area and has a 4 by 8 foot iron door, *f*, through which the fume is removed. The distributing flue *c* is 10 by 16 feet in section, extends the entire length of the bag house, and connects with each of the 16 cellars by means of a 42-inch hinged damper, *g*, opening outward into the distributing flue *c*. On top of this distributing flue is the return flue *h*, extending the entire length of the bag house and connected with each cellar by means of a 34-inch damper, *i*. The dampers open outward into the cellars. The return flue is connected with the main flue *a*, behind the fan, by means of a 6-foot sheet-iron downtake, *j*, and when the fume in any cellar is being sintered, the valve *g* from the distributing flue is closed and the valve *i* is open, so that the path is clear through the return flue *h* and through *j* to the main flue *a*. At the same time the cellar door *f* is open.

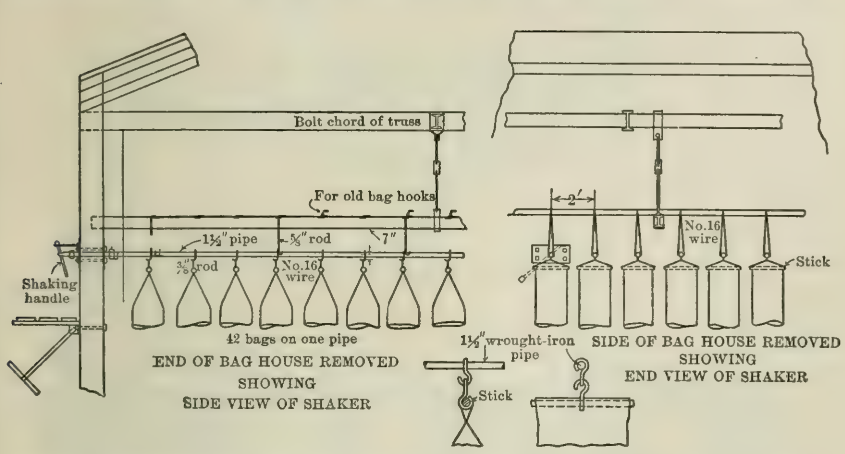

FIGURE 5.—Shaking device and two methods of hanging bags in bag house at Murray, Utah.

The thimble floor *e* is divided into four compartments, each containing 1,008 steel thimbles, 17 inches in diameter and 10 inches high. The thimbles are riveted to the steel floor. The bags, which are 30 feet long and 18 inches in diameter, and number 4,032 in the four compartments, are hung in one of the two ways shown in figure 5. This figure also illustrates the shaking device employed. At the bottom the bags are tied to the thimbles by means of wires. Figure 6 shows the fan house in some detail. The gases are drawn from the main flue *a* through the fan *x* and discharged into the distributing flue *c*. The bag house provides 570,012 feet of filtering area and filters 165,000 cubic feet of gas per minute, or at the rate of 3.45 square feet of surface per cubic foot of gas. With one compartment, or four cellars, shut down for sintering fume, there is available 2.59

square feet of filtering surface per cubic foot of gas per minute. This bag house was constructed in 1906 and cost $127,195.

BAG HOUSES AT TOOELE, UTAH.

Two bag houses were recently constructed at the International plant at Tooele, Utah. Their construction in general is similar to that of the bag house just described. One of the bag houses contains 960 woolen bags 31 feet high and 18 inches in diameter and is used to filter fume from the converters operating on lead-copper mattes. The other bag house contains 1,440 bags, some of wool and some of cotton fabric, and serves to filter the fume from the lead blast furnaces.

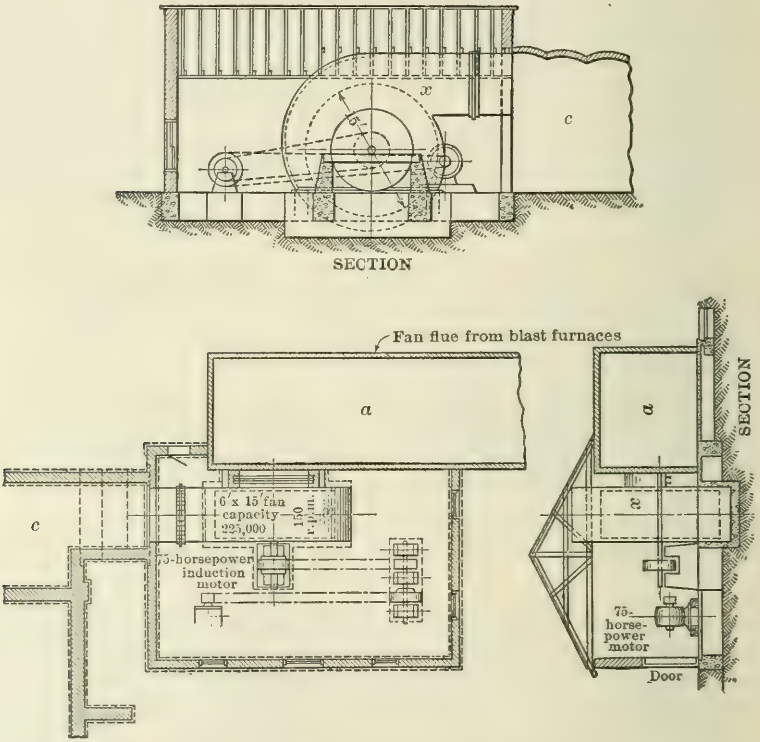
x
5
c
SECTION
Fan flue from blast furnaces
a
c
6' x 15' fan capacity 225,000
150 r.p.m.
x
75-horsepower induction motor
a
SECTION
x
75-horse-power motor
Door

FIGURE 6.—Details of fan house at Murray, Utah.

Figure 7 shows a cross section of one of these bag houses. The gas is discharged by a No. 20 Sirrocco fan, with a minimum capacity of 180,000 cubic feet per minute, into the brick distributing flue *a*, whence it passes through disk valves, *b*, into each of the eight smoke cellars *c*, and thence through the thimbles in a thimble floor, *d*, into the bags *e*, where the fume is filtered out, whence the clear gas escapes by means of a flue in the top of the bag house, shown in the section as a semicircle, *x*, to the chimney, 150 feet high and 15 feet in diameter. The manner of hanging the bags and an auxiliary shaking device for the bags to dislodge the fume is shown in figure 8. Usually, however, the shaking of the bags is accomplished by what is

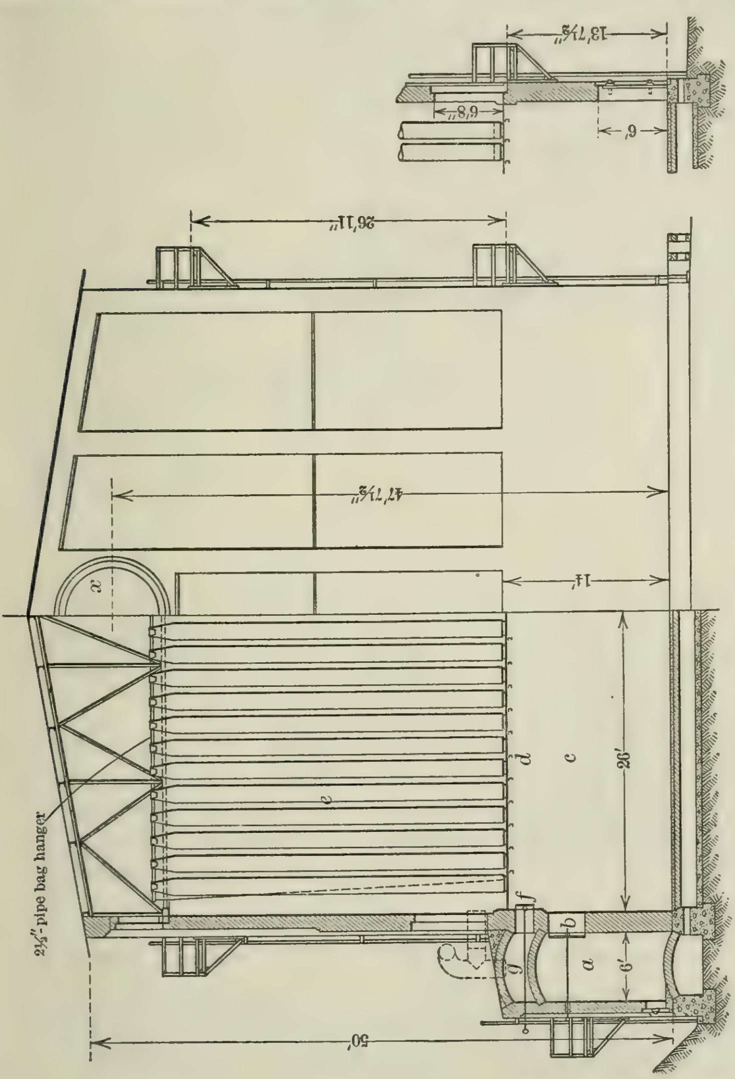

FIGURE 7.—Bag house at Tooele, Utah.

known as the reverse-current system. This comprises a small auxiliary flue, *g* (fig. 9), directly over the main flue *a* and arranged with openings into the smoke cellars. These openings are controlled by the disk valves *f*. One end of this auxiliary flue is connected with the intake or suction of a No. 4½ Sirrocco fan, the discharge from which passes back into the main flue. When the bags are to be shaken the disk valve *b* is closed and the valve *f* is open. This takes the pressure from the bags as the valve *b* shuts off the connection with the pressure discharge of the main fan and the valve *f* opens to the suction of the small fan mentioned. Hence the bags collapse and discharge their fume. By repeating the closing and opening of valves *b* and *f* a number of times, all the fume is readily dislodged. The valves are usually so operated once every eight hours.

Figure 9 shows the valve arrangement of the reverse-current bag-shaking system somewhat more in detail. At the Tooele plant the smoke from the Dwight-Lloyd sintering machines, which roast finely crushed lead sulphide ores, was formerly sent to the bag house. However, the elemental sulphur in fume from the sintering machines caused much trouble by setting fire to the bags. This practice has therefore been discontinued until a solution of the problem can be reached.

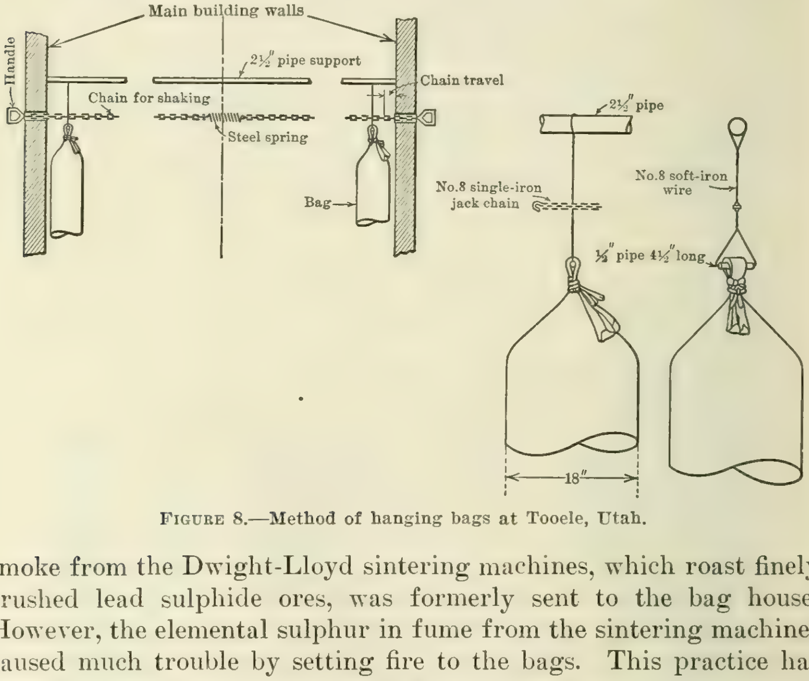

FIGURE 8.—Method of hanging bags at Tooele, Utah.

BAG-HOUSE PRACTICE AT PLANT AT MIDVALE, UTAH.

At the smelting plant at Midvale, Utah, methods were developed to filter all smelter smoke arising from a lead smelting plant, including that from blast furnaces, hand roasting reverberatories, Dwight-Lloyd sintering machines, Wedge mechanical furnaces and pot roasters. The plant employs what is known as the Sprague process for neutralizing the sulphuric acid content of the smoke.

Figure 10 shows a sketch of the smoke-filtering plant at this smelter. There are two bag houses, one (*e*) for blast-furnace smoke, and one (*f*) for the smoke from the roasting furnaces. Together they contain about 3,560 bags, each 33 feet long and 18 inches in diameter. The filtering surface is about 560,000 square feet, and 350,000 cubic feet of gas per minute is filtered. About 20 tons of fume is produced daily. The bag-house cellars terminate in hoppers as already described. The fan *c* takes the smoke from the blast-furnace flue *a* and discharges it into the distributing flue *d*, whence it passes through the cooling chambers and pipes *d′* and through the bag house *e*. At the fan *c* there is a small lime feeder, *b*, which consists of a screw conveyor feeding lime into a hopper at the discharge end of which is a push plate which pushes the finely crushed slacked lime into the fan housing, where the suction of the fan causes it to mix thoroughly with the smoke and neutralize the sulphuric acid. The fan *h* draws on the flues *j* coming from the Wedge furnaces, on the flue *k* coming from the pot roasters *l*, and on the flue *m* coming from the Dwight-Lloyd sintering machines *q*, forcing the smoke through the cooling chambers and pipes *g′* and then through the distributing flue *g* into the bag house *f*.

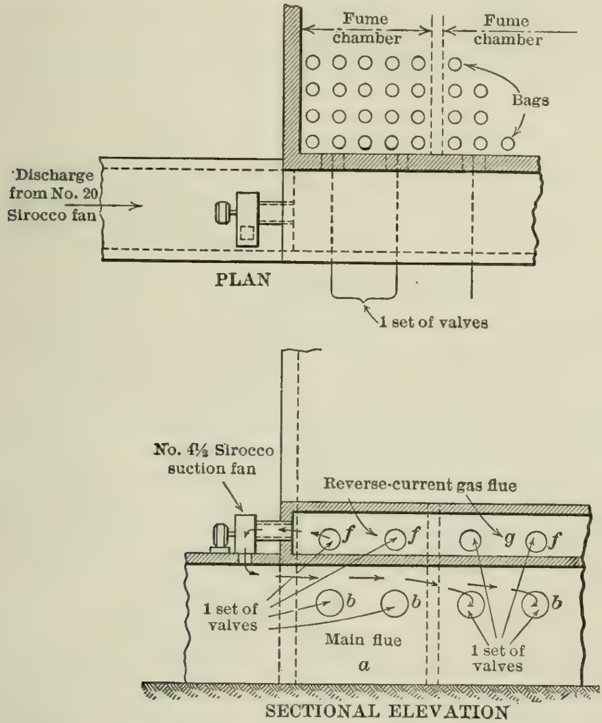

FIGURE 9.—Reverse-current shaking system used in bag house at Tooele, Utah.

At *p* are situated five small grate furnaces, on which crushed zinc sulphide ore or sphalerite concentrate mixed with coal is burnt by blowing air through the grate. The zinc oxide vapor arising from these furnaces is conducted by pipes to the flue *o* carrying the smoke from the Dwight-Lloyd sintering machines to the flue *m*. The volume of zinc vapor admitted to each flue is controlled by the plug valve *n*. At the end of the flue *j*, coming from the Wedge furnaces *r*, is a small fan, *s*, connected with a lime feeder. At this point finely slacked lime is blown into the flue. At *t* lime is blown into the flue *k* from the pot roasters and at *i* into the fan *h*. It is apparent therefore that for the roaster gases neutralization is effected by use of both zinc and lime. Thorough neutralization of these gases is essential, and it is stated that about 3,000 pounds of sulphuric acid is neutralized daily.

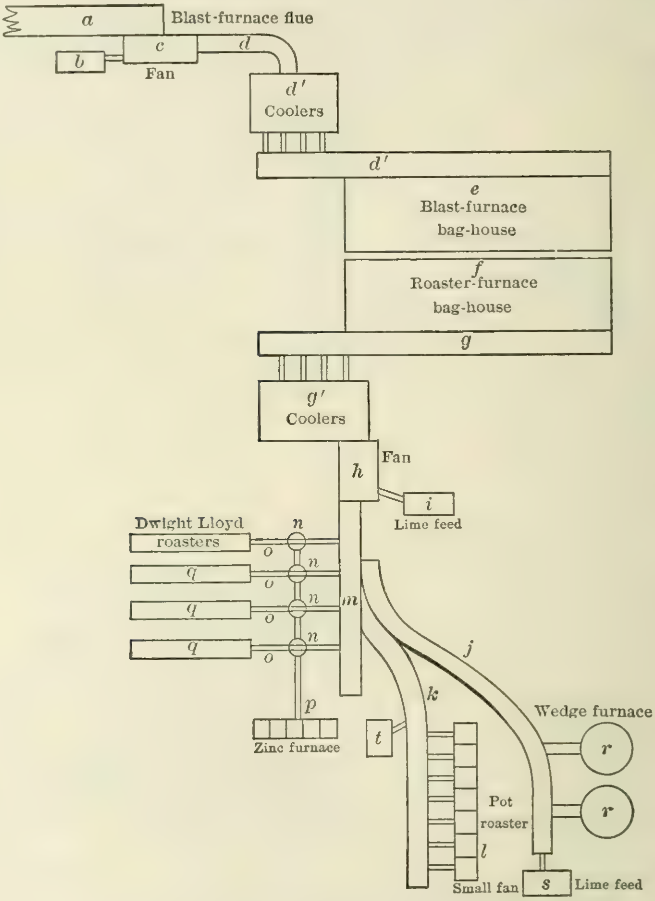

FIGURE 10.—Smoke-filtering plant at Midvale, Utah.

The quantity of zinc and lime fed is controlled by taking daily samples of the fume from the bag houses and determining their alkalinity. A certain excess of alkalinity is always carried to insure the neutralization of all acid. Although lime is fed also to the blast-furnace system, the measure is largely precautionary and not absolutely necessary. Zinc oxide is much more effective as a neutralizer than slacked lime, but on account of its expense is replaced in part by lime, which on the whole is efficient. In the absence of water, lime is not acted upon by sulphur dioxide gas to form sulphites, so that it need only be added in certain small excess over the percentage required for the neutralizing of the sulphur trioxide.

The Midvale plant is remarkable in the appearance of its stacks while in operation. There is no visible discharge from any stack of the plant, and at first sight the plant appears shut down. It is a shining example of what may be accomplished in this direction.

BAG HOUSE AT KENNET, CAL.

The plant of the Mammoth Smelting Co. at Kennet, Cal., is the only copper-smelting plant in the United States to which the bag house has been applied.

The smoke arising from copper blast furnaces and converters is filtered in a bag house 210 feet long and 63 feet wide, and with a main chamber 40 feet high, containing 2,960 woolen bags, each 34.5 feet long and 18 inches in diameter. The smoke enters the bag house at about 203° F. and the volume filtered is approximately 350,000 cubic feet per minute, which includes 70,000 to 150,000 cubic feet of cooling air drawn from the outside atmosphere, the amount depending upon the temperature. The gas comes from three blast furnaces and two converters. The furnaces smelt about 1,000 tons per day. Figure 11 presents a plan and elevation of the flue system and bag house.

ARRANGEMENT OF FLUE SYSTEM.

The gases from the furnaces and converters go through two long brick flues and dust chambers, *a*, parallel to the line of blast furnaces, into four steel pipes, *b*, each 8 feet in diameter, into a collecting chamber, *c*, 42 feet wide and 15 feet high, which contracts at one end and discharges into a steel flue, *d*, 15 by 15 feet in section. This flue leads to two 11-foot Sirrocco fans, which force the smoke each by an 8-foot flue, *e*, into the fan discharge chamber *f*, which is 20 by 15 feet in section and 160 feet long. In the main flue *d* there is vacuum of 1.7 inches of water, whereas in the fan discharge chamber *f* there is a pressure of about 3 inches. At the discharge of each fan is a device for feeding lime to the smoke stream similar to that described for the plant at Midvale. The pipes *e* are provided with dampers so as to regulate the amount of smoke handled by each fan. From the discharge chamber *f* the gases pass through a system of eight 4-foot cooling pipes, *g*, each about 200 feet long and of a U shape. Each pipe is provided with a butterfly valve. The cooling pipes discharge into the bag-house distributing chamber *h*, 13 by 14 feet in section and 210 feet long, into which a separate fan blows the necessary volume of cooling air. The distributing chamber *h* discharges through short pipes into the smoke cellars of the bag house.

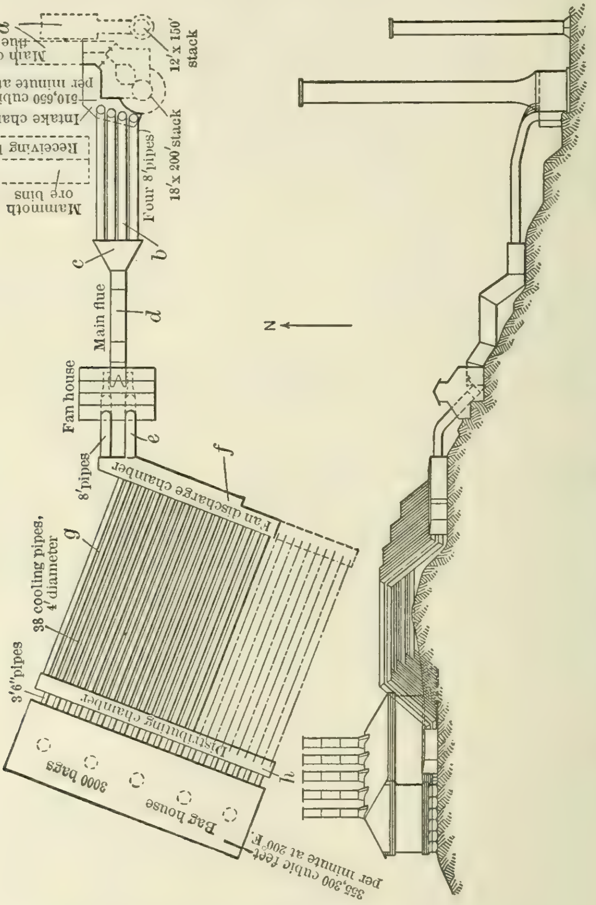

FIGURE 11.—Plan and elevation of bag house and flue system at Kennet, Cal.

NEUTRALIZATION OF SULPHUR TRIOXIDE IN FUME.

The filtering of gases from copper-blast furnaces and converters would not be possible without a neutralization of the sulphur trioxide content. The blast-furnace charge in this particular instance contains a considerable amount of zinc which under the oxidizing conditions of smelting is vaporized in part, with the formation of oxide of zinc. This most efficiently neutralizes the sulphur trioxide formed. Therefore the addition of extraneous zinc, as is done at Midvale, is not necessary. The addition of lime at the fans is said to be really not necessary, but is added as a precautionary measure. The bag house differs from others in the construction of hoppers under the cellars to facilitate the discharge of fume. The manner in which this is done has already been described on page 55. The fume produced is thoroughly oxidized and will not burn. About 16 to 18 tons is produced daily, in 1913 a large pile of it had accumulated in the yards of the company, no method having been devised for its economic treatment and the recovery of the metals contained therein. Table 3 indicates that its composition is essentially different from that of lead-furnace fume, in that the lead and arsenic contents are low and the zinc content is high. The bag house at this plant was installed to conform to court decrees that sulphuric acid should be practically absent from the smoke and that the sulphur dioxide should be reduced to less than 0.75 per cent. The bag house of course has no bearing on the sulphur-dioxide content mentioned, which is obtained by diluting the gases with air as described.

The bag house has five large, low, wooden stacks for the discharge of the filtered gases. Each of these stacks is 21 feet square. The idea of the low stacks with such large cross section is to thoroughly diffuse the gases from the bag house, and to aid in this result additional air is admitted to the bag house.

THE ELECTRICAL PRECIPITATION OF FUME.

GENERAL PRINCIPLES OF ELECTRICAL PRECIPITATION.

The precipitation of suspended matter, whether in gases or liquids, may be accelerated by electricity in the form of either direct or alternating current. Where an alternating current is applied the action consists for the most part in an agglomeration of the suspended particles into larger aggregates and a consequent more rapid settling of these aggregates under the influence of gravity. The application of the alternating current, however, is effective only when the masses of gas or liquid to be treated are fairly quiescent and a simple agglomeration of the suspended particles into larger aggregates is sufficient to effect separation by gravity. As regards large volumes of rapidly moving gases, such as occur in smelter flues, the agglomeration and settling process induced by the alternating current is too slow, even when the flues are expanded into large dust chambers. Consequently the application of the direct current, the action of which is quite different from that of the alternating current, is necessary.

USE OF DIRECT ELECTRIC CURRENT.

If a needle point connected to one side of a high-potential direct-current line be brought opposite a flat plate connected to the other side of the line the air space between becomes highly charged with electricity of the same sign as the needle point, irrespective of whether this is positive or negative. Any insulated body brought into this space instantly receives a charge of the same sign. If this body is free to move as is a floating particle, it is attracted to the plate of opposite charge and will move at a rate proportional to its charge and the potential gradient between the point and the plate. Even if there are no visible suspended particles, the gas molecules themselves undergo this same process, as is evidenced by a strong wind from the point to the plate, even in perfectly transparent gases. The familiar experiment of blowing out a candle flame by presenting it to such a charged point is another illustration of the same phenomenon. The gas is ionized[a] and some of the ions collect upon the solid particles, thereby charging them electrically. As the charged particles are within a strong electric field of constant polarity, they are driven to the collecting electrodes.

An alternating current of high potential or voltage is easily obtained, but the obtaining of a high-potential direct current is more difficult. Generators that furnish direct current at high potential are not built commercially, as they are impracticable. Therefore to obtain high-potential direct current a common custom is to take alternating current of any voltage available on a commercial line, transform it in stationary transformers to whatever voltage is desired (from 15,000 to 50,000 volts), and then obtain an intermittent direct current by means of a special rotary contact maker driven by a synchronous motor. The electrodes or terminals of the current employed are of two types, the first corresponding to the plate to which the particles are driven, and the second to the point or the discharge electrode. The plate electrode is usually made of either iron or lead, and presents no difficulty in construction.

The point electrode, however, must fulfill special conditions. In the early laboratory experiments with the process it was found that cotton-covered copper wire, by reason of the innumerable fine points presented by the threads of the cotton insulation, made a desirable discharge electrode. Under the conditions of acid vapors and high temperature this material, of course, can not be used, but a substitute was found in asbestos-covered wire, or a wire covered with mica, the fine filaments of the one and the scales of the other supplying the discharge point or edges of the excessive fineness required. The asbestos or mica was twisted with the wires or otherwise fastened to suitable metallic supports in such a way that the current had to pass only a short distance by surface leakage over them. The slight deposit of moisture or acid fume naturally settling on them serve to effect the conduction of the current.

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[a] The ionization of a gas is different from that of an ordinary liquid electrolyte. The actual gas ions under the conditions of pressure and temperature existing in the flue are probably fairly large aggregates or groups of undecomposed gas molecules clustered around electrons discharged from the corona of the negative discharge electrode. There are also probably a much smaller number of positively charged groups present, whose initial positive charge may be considered as due to taking away a negative electron from one of the neutral gas molecules.

APPLICATION IN SULPHURIC ACID PARTING PROCESS.

The first of the successful applications of the electrical precipitation process was to the waste gases and vapors from the sulphuric acid parting process for gold-silver bullion at the Selby smelter at Vallejo Junction, on San Francisco Bay, Cal. These gases, which amount to about 5,000 cubic feet per minute and contain a considerable proportion of sulphuric acid in the form of a fine mist, are conducted through a flue built of sheet lead 4 by 4 feet in cross section. In this flue (fig. 12) are hung a series of vertical lead plates, *a*, 4 inches wide, 4 feet long, and spaced 4 inches apart. Between each pair of plates is hung a lead-covered iron rod, *b*, carrying mica discharge material. These rods, which are the discharge electrodes, are supported on a grid work of bus bars, *c*, extending above the lead plates or collecting electrodes. The bus-bar grid work is connected to conductors which pass out through the sides of the flue to the insulators *d*. The collecting electrodes *a* are in electric connection with the lead sides of the flue, which, in turn, is grounded. The current is taken from the power circuit of the plant at 460 volts, 60 cycles, transformed to 17,000 volts, and is then converted into an intermittent direct current by a synchronous contact maker. The power consumption for this installation is about 2 kilowatts, which includes the driving current for the contact maker. The sulphuric acid particles collect on the lead plates and drip down into the flue, from which the accumulated acid is suitably discharged. The apparatus has been in successful use for over seven years. The gases discharged from the stack to which the lead flue leads are practically free from sulphuric acid.

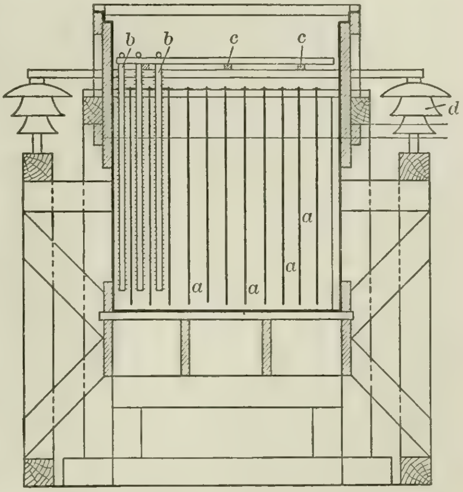

FIGURE 12.—Electric-precipitation apparatus used at Selby smelter at Vallejo Junction, Cal.

APPLICATION AT A COPPER SMELTER.

The electrical-precipitation process was applied on a large scale for the elimination of fume from smelter smoke at the plant of the Balaklala Copper Co. at Coram, Shasta County, Cal. This smelter, now (1914) shut down, daily treated about 700 to 1,000 tons of copper ore containing about 3 per cent copper and over 30 per cent sulphur. The largest part of this ore was smelted in blast furnaces, but about 10 per cent, or the fine material in the ore, was first roasted in four McDougal furnaces and then smelted in an oil-fired reverberatory furnace. There were also two converters for the conversion of matte into blister copper. All of these furnaces discharged into a common flue 18 by 20 feet in cross section. The total volume of smoke was 250,000 to 500,000 cubic feet per minute, giving a linear velocity in the flue of 10 to 20 feet per second. The nature of the installation is shown in figures 13 and 14. The gases from the furnaces in flue *a* (fig. 13) were sent through nine precipitating units, *b*, from which they passed to the outlet flue, *c*, then through the two fans *d* and out through the stack *e*. The gases entered the precipitating units at 100° to 150° C. Ordinarily, the fans were not in operation, but when the furnace charges were especially high in sulphur, it was necessary to use the fans in order to draw in diluting air and mix it with the smoke stream, so that the discharge from the stack would contain less than 0.75 per cent sulphur dioxide to conform to a court decree.

Figure 14 represents a cross section of one of the precipitating units. The collecting electrodes, each 6 inches wide and 10 feet high, made of No. 10 sheet iron, are shown at *a*. The discharge electrodes, consisting of two iron-wire strands, between which was twisted the discharge material for which both asbestos and mica preparations were used at this plant, are shown at *b*. The collecting electrodes *a* were carried by bars, *c*, which were connected directly to the frame of the chambers themselves and thus grounded. The discharge electrodes *b* were spanned by springs *d* between a system of bus bars, *e*, which were carried on externally placed insulators *f*. To the auxiliary chamber *g* surrounding the insulators a small regulated amount of air was admitted to prevent conductive dust or fume from settling on the insulators and thus causing a connection with the sides of the chamber, to which the collecting electrodes were connected. The cam and shaker rod *h*, which extended across the middle of the unit, was designed for the purpose of shaking the collecting electrodes *a* to dislodge the accumulated fume and cause it to drop into the hopper *i*. In actual operation it was found easier to remove the cover *j* after the current had been cut from the unit and shake the electrodes by hand every six or eight hours. The accumulated fume in the hopper *i* was removed by the means of a screw conveyor. In each precipitating unit there were 24 rows of 24 electrodes of each type.

The current used was taken from a three-phase power circuit at 2,300 volts, 60 cycles, which, after having been transformed by stationary transformers to 30,000 volts, was converted into an intermittent direct current by 10 contact makers, driven by synchronous motors, one contact maker for each unit, with an extra one for use in case of accident. The amount of power consumed was about 120 kilowatts. Tests of the apparatus showed that the process removed

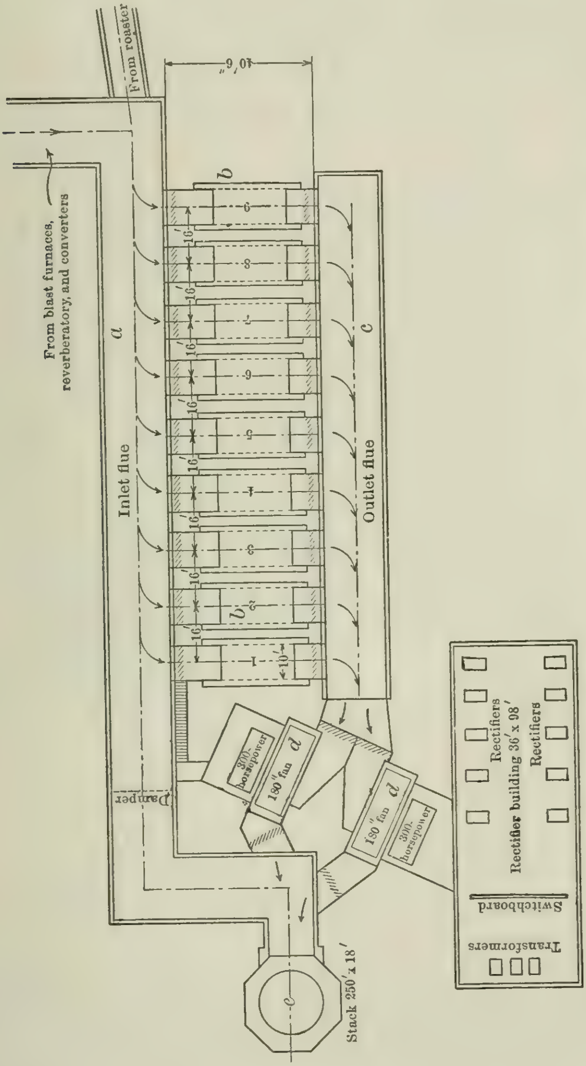

FIGURE 13.—General arrangement of electrical-precipitation plant at Coram, Cal.

nearly 90 per cent of the total solids in the smoke stream. The amount of fume recovered daily was 6 to 8 tons.

One of the most serious difficulties encountered in this installation was the maintenance of the conductivity of the fine fibers of the discharge electrodes. Under ordinary conditions, smelter smoke will contain enough sulphur trioxide or sulphuric acid, which condenses on the fibers, to make them conductive, but in this instance the furnace charge contained a considerable quantity of zinc which formed zinc sulphate. The lack of sulphuric acid greatly reduces the conductivity of the fibers. This difficulty, however, has been overcome in recent work by the use of higher potentials and better designed electrodes by means of which the necessity for the fine discharge fibers, such as the asbestos and mica represented, has been obviated.

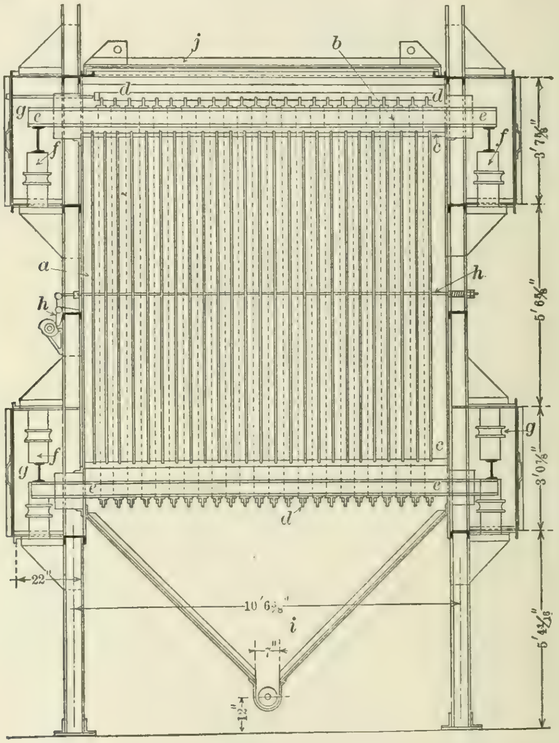

FIGURE 14.—Cross section of precipitation unit in electrical-precipitation plant at Coram, Cal.

The Coram installation is not now in operation, as the smelter was closed in September, 1911, for failure to conform to a court decree. The process, however, may be considered to have been successfully applied and there is little doubt but that with additional experimentation such changes could have been devised as would have made the process entirely successful.

RECENT APPLICATION IN COPPER REFINING.

A recent application of the electrical-precipitation process is an installation at Perth Amboy, N. J., to the gases from furnaces smelting the high-grade residues or slimes from electrolytic copper refining. The material is high in gold and silver contents and contains volatile constituents, such as tellurium, selenium, and lead, and the fume condensed from the gases contains appreciable quantities of precious metal.

The process was also applied experimentally to the smoke from the copper converters at Garfield, Utah. The matte converted at this plant contains somewhat more lead than is usual for copper matte. The lead is volatilized during the conversion and passes to the smoke. The process was applied to this material successfully and in somewhat different form than already described. The so-called "tubular treaters" were used. These consist of a number of pipes, each 10 feet long and 5 inches in diameter, forming a collecting electrode, down the center of which passes the discharge electrode in the form either of single wires or of a metal rod, with four or more radial wings of sheet metal to act as the discharge edges. The pipes may be of sheet lead, vitrified tile, or wood, dependent upon conditions. The smoke enters the pipes at the bottom, the fume being precipitated on the walls of the pipes, eventually dropping into a collecting hopper; the gases escape. In Plate V, *A* and *B*, is shown such a tubular treater with the current off and with it on. Voltages up to 50,000 were used. A permanent installation[a] for the treatment of all the converter smoke is now in operation.

METHODS FOR REMOVAL OF SULPHUR DIOXIDE FROM SMELTER SMOKE.

The effect of sulphur dioxide has been fully discussed in the preceding pages. Obviously, if its concentration in smelter smoke discharged from chimneys reaches a certain figure, the value of which at the present time has not been determined, the natural diffusive forces do not act quickly enough to dilute the smoke stream to such an extent as to prevent all damage. The question as to whether sulphur dioxide or the solids and sulphuric acid discharged as fume are the chief cause of damage has been widely discussed. There is, however, no question but that both have caused damage. Lead-smelting plants discharge gases that on the whole are comparatively low in sulphur dioxide, and it is probable that damage formerly caused by the smoke stream from such plants was due in large part to the solids. In copper smelting the sulphur content of the furnace charges is much higher, and it is probable that such damage as has been done was largely due to sulphur dioxide. Therefore much effort has been directed toward finding methods for the removal or destruction of this substance, but, to the present time, with little promise of success. The amount of sulphur dioxide discharged daily by all the smelting plants of the country is enormous, and the utilization of all of it in some form, such as sulphuric acid or sulphur, is at present not feasible, as the amount of these substances produced would many times supply the possible market demand.

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[a] See Howard, W. H., Electrical fume precipitation at Garfield: Trans. Am. Inst. Min. Eng., Bull. 92, 1914, p. 2029.

UTILIZATION OF SULPHUR DIOXIDE AS BY-PRODUCT DESIRABLE.

The first thought, of course, that comes to the engineer, is to transform this now useless substance into some valuable by-product, such as the sulphuric acid or sulphur mentioned above. The solution of the problem along these lines is so influenced by local conditions that no general statements can safely be made. In the South, there is a considerable demand for cheap sulphuric acid in connection with the treatment of phosphate rock in the manufacture of fertilizer, and also for the purpose of converting the ammonia by-product of coking ovens into ammonium sulphate. This demand made it possible, in a large measure, to solve the smoke problem in the vicinity of Ducktown and Copperhill, Tenn., where two smelting plants manufacture sulphuric acid from the sulphur dioxide in smelter smoke. The smelters of the West are not favorably situated in this respect, at least at present, as the market for sulphuric acid is comparatively small. In Utah, however, there are large phosphate deposits which no doubt will be utilized in time, so that a great demand for cheap acid may develop. As already stated, the problem is always local. At Anaconda the question of treating the tailings or refuse product from the concentration mills for the recovery of their copper content is now being seriously considered. The process that will be applied is one of roasting the tailings and leaching the roasted product with sulphuric acid. This sulphuric acid will probably be manufactured locally from the gases of the McDougal furnaces that roast the concentrate of the mills. Although all of the sulphur dioxide produced at Anaconda can not be utilized, the removal of a part of it from the smoke stream will have a generally desirable effect.[a]

The Hall and the Thiogen processes, now prominent in the amelioration of the smoke difficulty, are designed to remove sulphur from the smoke stream in the form of elemental sulphur. The Hall process eliminates the sulphur in the ores direct in the form of elemental

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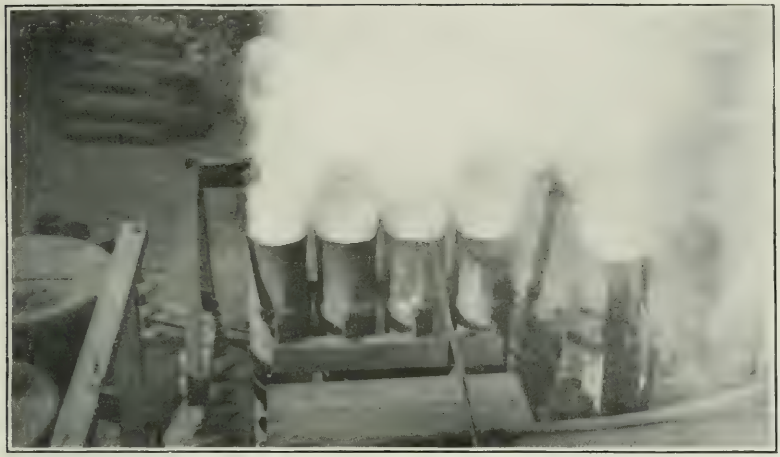
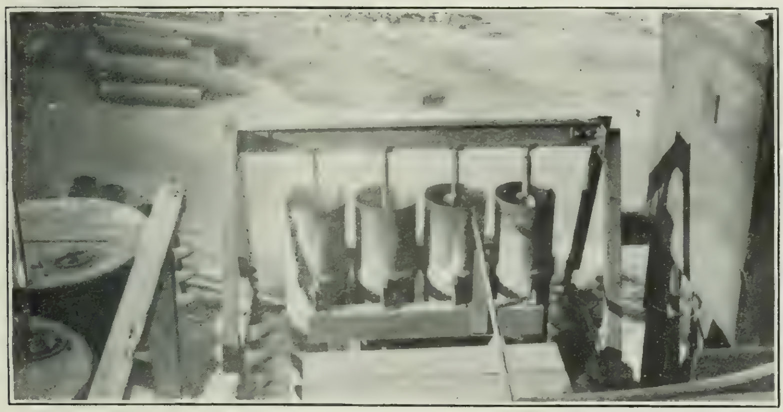
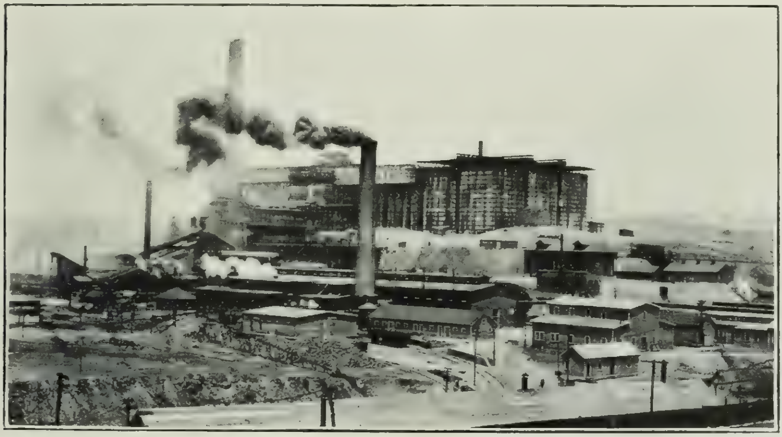
[a] Incidentally another desirable feature is that the spent liquors containing iron sulphate and other salts from the leaching process can be dumped back over the tailings and thus cement the tailings into a coherent mass and prevent their blowing away as fine dust clouds, which are at present a considerable nuisance in certain parts of the surrounding valley.



A. ELECTRICAL TUBULAR PRECIPITATOR, CURRENT OFF. SMOKE IS LADEN WITH FUME.



B. ELECTRICAL TUBULAR PRECIPITATOR, CURRENT ON. SMOKE IS INVISIBLE.



C. SMELTER AND ACID PLANT AT COPPERHILL, TENN.

sulphur and prevents the formation of sulphur dioxide; the Thiogen process destroys the sulphur dioxide in the smoke stream, with the production of elemental sulphur. The leading idea here also is the winning of a valuable by-product, which will yield a profit or at least meet the expense of the applied process. Elemental sulphur at present has a ready market, but it is easy to show that the possible production of sulphur by these means will glut the market. The problem is again a local one.

If the sulphur dioxide in smelter smoke can not be converted into valuable by-products, the problem becomes one of finding a cheap means to destroy the sulphur dioxide and convert it into a harmless substance. From this standpoint, although for obvious reasons the sulphur dioxide may not be converted into sulphuric acid, it might still be converted into elemental sulphur, which could be stored in isolated places. At various times many suggestions have been made for the destruction or removal of sulphur dioxide, such as its removal by solution in water or its absorption by limewater, with the formation of lime sulphite, all of which, except under certain local conditions when they may become applicable, in the end give rise to just as great a nuisance as does the original substance. At present the best-known method for minimizing the nuisance of sulphur dioxide in smelter smoke is to dilute the smoke and diffuse the dioxide to such an extent that it will be practically harmless.

MANUFACTURE OF SULPHURIC ACID FROM SMELTER SMOKE.

In this country two neighboring plants manufacture sulphuric acid from smelter smoke. One, that of the Tennessee Copper Co., is at Copperhill, Tenn., and the other, that of the Ducktown company, is at Isabella, Tenn. Both plants practice pyritic smelting, the ores consisting largely of pyrrhotite, cupriferous pyrite, and chalcopyrite, with smaller amounts of other minerals. The sulphur content of the furnace charge is high, about 21 per cent. The copper in the ores is about 2 per cent. If sulphuric acid is to be manufactured from sulphur dioxide in smelter smoke, certain conditions must necessarily be fulfilled. The chief one is that the gas have a high enough sulphur dioxide content—not less than about 4.5 to 5 per cent. The proportion of carbon dioxide gas should not be over 4 per cent.

Methods have been proposed to concentrate sulphur dioxide by passing the smoke stream upward through towers filled with coke or other material, over which a stream of cold water is constantly trickling. The water discharged from the towers will contain considerable sulphur dioxide, and if it be heated this gas will be liberated. Whether the process would afford sufficient concentration under existing conditions is questionable, and the added step might inordinately increase the expense. It is safe to state that sulphuric acid can be manufactured commercially only in those plants in which the gas contains the required amount of sulphur dioxide without concentration. This requirement eliminates many smelters and limits others to gas from certain furnaces only, such as the roasting furnaces, which treat charges high in sulphur.

DESCRIPTION OF COPPERHILL AND ISABELLA PLANTS.

At Copperhill, the gases from the four blast furnaces smelting the crude or green ore are sent to the acid plant. The gases from the converters and from the blast furnaces that re-smelt the matte from the green ore furnaces into a more concentrated product are sent directly to the stack, as they do not contain sufficient sulphur dioxide.

Figure 15 shows the various steps of the acid process. The path of the gas and acid is indicated by light lines with arrows. The furnace gas has a composition approximately as follows: Carbon dioxide, 3.5 per cent; sulphur dioxide, 5.3 per cent; oxygen, 8 to 10 per cent; remainder, nitrogen. This gas passes from the comparatively tight furnace tops of the four furnaces by means of individual downtakes into the acid-plant dust chamber, from which it passes by a cross flue into a large distributing flue or secondary dust chamber, from which in turn it passes by two cross flues into the two niter houses, where the nitrous oxides are added.

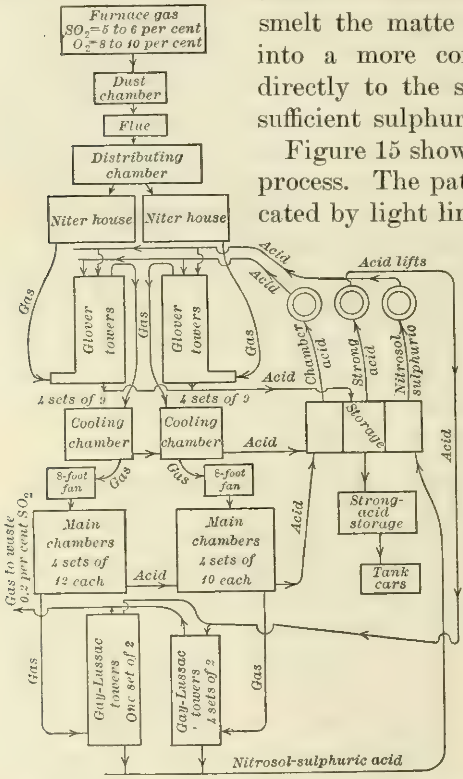
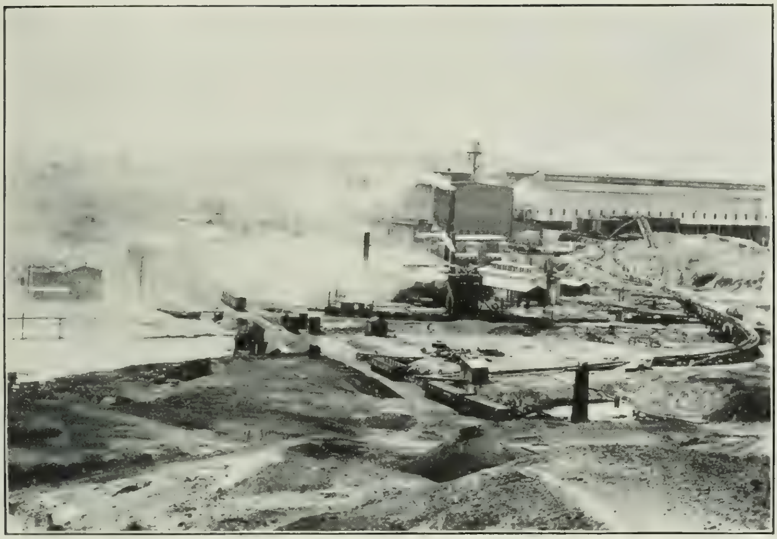


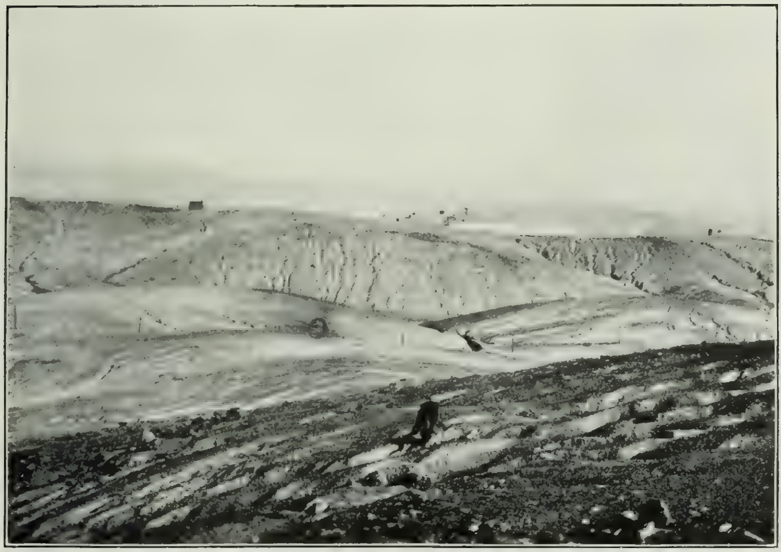
FIGURE 15.—Various steps of process of making sulphuric acid from smoke of smelter at Copperhill, Tenn.

Plate V, *C*, shows a general view of the smelting and acid plants. Although acid is manufactured from the gases, the main stack in the rear of the picture is seen to be discharging fume. This is due to the fact that only part of the gas was going to the acid plant, as already stated. The stack in the foreground is the boiler stack.

Plate VI, *A*, shows a view of the Isabella acid plant and smelter, which treats all of its smoke for acid. Plate VI, *B*, is a view near the Isabella plant, showing damage due to the heap roasting formerly employed.



A. SMELTER AND ACID PLANT AT ISABELLA, TENN.



B. VIEW NEAR DUCKTOWN, TENN., SHOWING DAMAGE DONE BY HEAP ROASTING.

PRODUCTION OF ACID AT COPPERHILL.

In 1911 the plant at Copperhill, Tenn., smelted 383,248 tons of sulphide ore. The gas from the furnaces was made into acid. The ore contained 23.4 per cent sulphur, or 89,774 tons, of which 70,100 tons was made into about 150,000 tons of acid with a specific gravity of 60° B. In 1912 the same plant produced 192,084 tons of acid, or at the rate of almost 600 tons of acid daily. The capacity of the plant is about 700 tons per day. The total acid production in the United States in 1912 was 3,462,000 long tons of acid with a specific gravity of 50° B. (62.18 per cent pure). Of this production about 270,000 tons was derived as a by-product from copper smelting and 292,748 tons as a by-product from zinc smelting, a total of 562,748 tons derived as by-products from metallurgical works.

METHOD EMPLOYED AT COPPERHILL PLANT.

The manner in which the gas used for acid making is produced differs somewhat at the two plants. At the Copperhill plant the sulphide ores are smelted by pyritic smelting in blast furnaces with excess air, the excess being blown in at the tuyères. This excess of air is such that the gases issuing from the top of the furnaces contain 8 to 10 per cent oxygen, the proportion required in acid making. In consequence of this excess air, the gases from the furnace have the high temperature of about 916° F., and contain practically no elemental sulphur in the form of vapor. They enter the niter house at approximately the same temperature. The amount of air used by the furnaces is about 59,000 cubic feet per ton of furnace charge, exclusive of coke.

METHOD EMPLOYED AT ISABELLA PLANT.

At the Isabella plant the sulphide ores are smelted pyritically in blast furnaces, but with only the volume of air normally required to carry on the smelting. In consequence the top of the furnace is comparatively cool, and the gases contain no excess oxygen but considerable elemental sulphur. The gases normally contain 7 to 8 per cent sulphur dioxide, 4 to 5 per cent carbon dioxide, 0.5 to 1 per cent free oxygen, and about 1 per cent carbon monoxide and appreciable sulphur vapor. These gases pass into a dust chamber and flue and thence to the acid plant. The flue leading from the dust chamber is connected with an air pipe from the blowers that furnish air for the blast furnaces. This pipe supplies the air that must be added to the furnace gases to give them the oxygen content necessary in acid making. At the point where the air enters the flue the sulphur vapor burns to sulphur dioxide. The combustion of the sulphur at this point raises the temperature of the gases to 900° to

1,000° F., the temperature necessary in the niter house, and the addition of air reduces the sulphur dioxide content of the gas to about 4.5 to 5 per cent. In other respects the process of making acid at the two plants is very similar. The gases discharged from the acid works are practically free from sulphur dioxide, containing normally about 0.2 per cent, which is not sufficient to cause damage.

THE PRODUCTION OF ELEMENTAL SULPHUR.

THE HALL PROCESS.

DIRECT APPLICATION OF PROCESS.

The Hall process is the invention of William A. Hall, and designs to remove sulphur directly from sulphide ores in the form of elemental sulphur, thus preventing the formation of sulphur dioxide. Proposal has been made to apply the process to the roasting of sulphide ores in furnaces like the McDougal or Wedge multiple-hearth furnaces. Essentially, it consists of submitting the ore to closely controlled oxidation in the presence of water vapor, resulting in the conversion of the sulphides of the metals into oxides, and the liberation of the combined sulphur in the form of elemental sulphur which is collected in water or by other suitable methods. In the process the roasting furnace is fitted with burners for the combustion of oil gas or any gas of high calorific power, although ordinary producer gas may be used. The furnace is tightly inclosed, and the admission of air is accurately controlled. By a proper adjustment of the burners an oxidizing, a neutral, or a reducing atmosphere may be attained in the furnace. It is stated that a furnace operated in this manner attains the same capacity as if it were roasting ore in the usual manner, proportionately to the sulphur eliminated.

PRODUCTS AND CHEMISTRY OF THE PROCESS.

The product of the furnace consists of the oxides of the metals and some undecomposed sulphides, the amount of the latter depending upon how much sulphur it is desired to leave in the calcines or roasted product. The chemistry of the process,[a] pyrite being taken as the sulphide mineral, is probably as follows: One atom of sulphur in the pyrite is readily distilled as elemental sulphur in a neutral or reducing atmosphere. The iron sulphide remaining, at a temperature between 700° and 900° C., which is attained by the combustion of gas or oil at the burners, is converted by the action of water vapor probably into magnetic iron oxide and sulphureted hydrogen. The sulphureted hydrogen is converted to elemental sulphur and water vapor by the limited proportion of atmospheric oxygen present, aided perhaps by the presence of some sulphur dioxide.

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[a] The chemistry of the process is at present under investigation, and the statements here made are provisional only and subject to correction.

The reaction taken as a whole is exothermic; that is, it liberates heat to the extent of 753 calories per kilogram of iron sulphide entering into the reaction, provided the final products of the reaction are assumed to be magnetic oxide and sulphur. Water vapor is necessary in the process for the purpose of furnishing hydrogen to temporarily combine with the sulphur during the decomposition of the iron sulphide by oxygen. It is apparent from the reactions that considerable atmospheric oxygen is needed, so that the iron may be oxidized. Theoretically the product may consist of either ferric oxide or magnetic oxide, and it is this fact that permits a considerable adjustment of conditions in the furnace, for even if a mixture of these oxides be produced the result is still satisfactory. If the conditions in the furnace are maintained too strongly reducing, there is not sufficient oxygen to decompose all of the hydrogen sulphide formed and some escapes with the gases from the furnace. If, on the other hand, the conditions are maintained too strongly oxidizing, the excess oxygen over that required for the iron oxidizes sulphur to sulphur dioxide, and this will be present in the gases coming from the furnaces. The success of the process, therefore, depends upon a close adjustment of the volume of air entering at the burners. The water vapor or steam needed may be injected at the burner, or a sufficient amount may result from the combustion of the hydrogen in the fuel gas that is being used. It has also been noted that organic sulphur compounds form to some extent during the roasting, but little information on this phase of the process is at present available.

The sulphur escapes from the furnace as vapor of sulphur in the gases, and it is stated that if these gases be submitted to the action of water, as, for instance, in centrifugal washers, such as the Thiesen or Feld washer, used to wash iron blast-furnace gases, the sulphur may be readily removed in the water, from which it can be settled out. It is also possible that the electrical-precipitation process may be applied, for recent experiments with the Feld washer show that the washing method presents unusual difficulties. It is stated that sulphur can be produced by this process at a cost of $3 to $5 per ton, but recent experiments seem to show this estimate to be too low. During 1913 sulphur was quoted at about $22 per ton, New York. The fuel consumption in the process is said not to be more than 10 per cent of the weight of the ore roasted. The process is being investigated experimentally on a large scale in the copper-smelting plant at Coram, Cal.

PROSPECTS FOR SUCCESSFUL USE OF PROCESS.

The process is one of considerable promise, but it can not be looked upon, even if successful, as solving the smoke problem as a whole. It may solve the problem locally, dependent upon conditions. One of the great advances in the metallurgy of copper within the last 10 years is the general adoption of the process of smelting sulphide ores in the raw state in the blast furnaces, the fuel value of the iron sulphide being utilized. This plan has decidedly lessened the consumption of coke and the cost of smelting. At present whenever sulphide-copper ores are of the proper physical character—that is, in not too fine a state of division—they are smelted to copper matte in the blast furnace without any preliminary roasting. On the other hand, sulphide ores that break very fine in the mine, or sulphide concentrate, must first be roasted for the elimination of a large part of the sulphur, after which it is smelted in reverberatory furnaces. The Hall process would find its application to those ores that must first be roasted. The California copper-smelting plants in Shasta County, at one of which the process is now being applied, smelt the ores largely in blast furnaces. Whether the grade of ore will permit any other form of smelting, such as roasting by the Hall process and reverberatory smelting of the resultant calcines, is a question that remains to be settled. It is, however, true that the cost of coke is high ($11 per ton), whereas crude oil for roasting and reverberatory smelting is cheap (2½ cents per gallon). Recent work at Coram on the Hall process shows, on steady runs of a week or more, an oil consumption of 20 gallons per ton of Balaklala ore. One 18-foot McDougal roasting furnace had a capacity of 24 tons on ore of such fineness as to pass a ½-inch screen. The sulphur content of the calcines was 6 to 8 per cent. The same furnace had a capacity of 32 tons on ore crushed to pass a 10-mesh screen, the calcine containing 3 to 5 per cent sulphur.

THE THIOGEN PROCESSES.

The Thiogen Co. has two processes, both based on the same general chemical reactions, but differing widely in their application and possibilities.

CHEMISTRY OF "DRY PROCESS."

The so-called "dry process" is based on the fact that when sulphur-dioxide gas of suitable concentration is mixed with hydrocarbon gas or practically any refining gas, and the mixture of such gases is passed over a heated basic sulphide such as calcium sulphide (CaS) or barium sulphide (BaS), a reaction takes place in accordance with the following equations:

$$2CaS+3SO_2=2CaSO_3+3S$$
$$2CaSO_3+2CH_2=2CaS+2CO_2+2H_2O$$

In this general reaction the base used plays a purely catalytic or cycle rôle. If pure gas were used the result of the reaction would be in accordance with the equation:

$2CH_2$[a] $+3SO_2=2CO_2+2H_2O+3S$

The last reaction does not take place, however, to any appreciable extent in the absence of a base.

Essential to the commercial success of this process are several conditions, as follows:

The sulphur-dioxide gas must have a concentration of not less than 8 per cent by volume. Below this concentration the reaction is incomplete, and although the gas is completely decomposed there is formed a large amount of gaseous organic compounds by the combinations of the sulphur formed with the various constituents of the hydrocarbon gas used. With a gas carrying about 11 or 12 per cent sulphur dioxide by volume, the tendency to the formation of these organic sulphur compounds is greatly decreased, and other conditions being correct sulphur is formed in nearly theoretical proportions and of a high degree of purity.

The gases, both sulphur bearing and hydrocarbon, must be free from mechanical impurities, such as flue dust or soot, as any solids carried to the basic material soon form a coating over it and destroy its activity.

The reaction starts at a temperature close to 750° C., and should not be allowed to go above 900° C., as the sulphide has a corrosive action at the higher temperatures.

Any free oxygen in the gas must be combined with the hydrocarbons before the reaction will approach completion. If the proportion of free oxygen present is large, the heat developed from its combination with the hydrocarbon gas presents a difficult mechanical problem both in its disposition and its control.

On account of the various controlling and limiting factors, this process seems applicable only to gases of high and uniform sulphur-dioxide concentration, such as roaster gases and by-passed sintering-machine gases, unless a part of the final sulphur product is continuously used to raise the concentration of sulphur dioxide in the gases before treatment.

PROCEDURE IN "DRY PROCESS."

The general method of procedure in the "dry process" is as follows:

The hot gas is taken from its source, such as a roaster, and enters directly into a steel combination heat radiator and dust collector filled with sets of vertical pipes through which the gases, after having been cleaned and cooled, are returned and partly preheated. The proportion of cool gas passing through the transfer tubes is controlled by means of a by-pass, and in this way the exit temperature of the hot, uncleaned gases from the radiator is never allowed to fall below 280° C.

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[a] The formula CH_2 is here used to represent gases of the olefin group of hydrocarbons, of which ethylene or olefiant gas (C_2H_4) is the type.

The uncleaned gases at this temperature are taken into a water-jacketed, lead-coil combination cooler and scrubber and are completely cooled and cleaned of all mechanical impurities and solids. Sulphuric acid is used for the scrubbing.

The gas then passes through a filter to remove all acid mist carried over from the scrubber. From the filter the dry, clean gas enters the suction side of a positive blower and is passed through the tubes in the steel radiator, as before mentioned.

The roaster gas is next mixed with the hydrocarbon gas in the correct proportions, and the combined gases passed to the contact chamber. This chamber is double walled and divided into four outside chambers and one large inner chamber. The inner chamber is filled with the contact material (CaS) and is also traversed by a large number of fire-clay pipes. By a peculiar arrangement the mixed gases enter in parallel the two outer chambers, and then have to pass through the clay pipes into the second chambers, and from there downward to the base of the contact chamber, which the gases enter from both sides. A great amount of heat is developed in the contact chamber by the reaction, and this heat is radiated through the clay tubes and preheats the mixed gases to the reaction temperature before they enter the base of the contact chamber. The transference of heat also serves to keep down the temperature of the contact chamber, which would otherwise be excessively hot.

The hot exit gases from the contact chamber, now carrying sulphur vapor, are passed through the flues of a boiler-type condenser. The heat from the gases is used to generate steam, and this steam is kept at a pressure of about 30 pounds, insuring the correct temperature in the tubes for the sulphur to condense into its liquid form and flow freely.

The final waste gases, free from sulphur, are discharged from a small stack.

CHEMISTRY OF "WET PROCESS."

The so-called "wet process" of the Thiogen Co. is based on the fact that when a basic sulphide such as calcium sulphide or barium sulphide, either in finely divided water suspension or in solution, is treated with sulphur dioxide gas free from carbon dioxide the following reaction takes place in the cold:

$$2Ca(or Ba)S+3SO_2=2Ca(or Ba)SO_3+3S.$$

The absorption and reduction of the sulphur dioxide gas in a water suspension of calcium sulphide was first tried, and with gases free from carbon dioxide was accomplished satisfactorily with only a slight loss of sulphur as hydrogen sulphide gas. However, instead of the reaction proceeding strictly according to the above equation, there was formed a large amount of thiosulphates, dithionates, trithionates, and tetrathionates, and bisulphites, trisulphites, and tetrasulphites of calcium, all of which were soluble up to a certain concentration. The formation of such compounds resulted unfavorably in two ways, as follows:

(1) The water or liquor of suspension could not be thrown away, as to do so would have entailed a large loss of sulphur and calcium.

(2) The specific gravity of the solution, after having been used as a liquor of suspension, with repeated additions of fresh calcium sulphide after each filtration of the precipitate, gradually raised, unless kept well cooled, to about 1.3, owing to the large proportion of sulphur compounds of calcium in solution. At this gravity the settling of the sludge (calcium sulphite and sulphur) was slow and unsatisfactory. Filtration, likewise, was unsatisfactory, as the thiosulphates in solution crystallized slowly and tended to completely clog the filters by precipitating in the meshes of the filter itself. For these reasons, calcium was abandoned, temporarily at least, and barium used.

Barium sulphide is rapidly soluble in water, whereas calcium sulphide is not. If any thiosulphates or other sulphur compounds of barium are formed in addition to the barium sulphite they are practically insoluble and precipitate rapidly along with the main products of the reaction, barium sulphite and sulphur.

The specific gravity of the solution rises only slightly above 1.00, and the settling of the solids is so rapid and complete as to do away with the necessity for any filtration except for the final removal of moisture from the settled precipitates themselves.

The presence of carbon dioxide in the gases to be treated causes the formation of hydrogen sulphide in large proportions, and for this reason it was found advisable to absorb the sulphur dioxide out of the gas in water and to treat the resulting solution with finely powdered barium sulphide in the dry state. The action is rapid and complete, and, as before stated, the precipitates settle rapidly, allowing the clear overflow liquor to be immediately used again for absorption.

PROCEDURE IN "WET PROCESS."

The general method of procedure in the "wet process" is as follows:

The gas containing sulphur dioxide is taken from its source and thoroughly cooled and scrubbed as in the "dry process." It is then passed through three absorbing towers in series. The towers are filled with hollow tiles especially designed, and present a large absorption surface; the gas passes through slowly and builds up little pressure. The absorbing liquor enters at the top of the last tower and comes down in series through the three towers so that the final flow of the liquor is through the incoming gas of highest sulphur dioxide concentration.

The liquor carrying the sulphur dioxide in solution enters the suction side of a centrifugal pump. Part of the discharge of this pump is taken off and enters the top of a vertical cone-shaped incorporator, into which also the finely powdered barium sulphide is admitted by means of a closely adjusted screw feed. The incorporator discharges into the inlet of a small contrifugal pump, which in turn discharges into the inlet of the large pump and is there mixed with the main stream of liquor from the absorbing towers.

The discharge from the large pump passes through a system of cone-bottomed agitating tanks and through a system of settling tanks in series. The overflow from the last settling tank returns to the absorbing towers. Each settling tank is designed to hold a day's run of solids (sulphur and barium sulphite). The tanks have filter bottoms and draw-off outlets on the sides. One tank is cut out of the system each day, and the supernatent liquor, after it has settled to the lowest point, is drawn off. The filter pump is then started and the precipitate is filtered. When filtration is completed a discharge door in the bottom of the tank is opened and an excavator discharges the filtered precipitates on a conveyor belt below which carries them to the dryer.

The drying is done with waste gases and at a low temperature, and the dried precipitates then go to a sulphur vaporizer which is built on the order of a muffle roaster with cast-iron floors. In this device the sulphur is volatilized and removed by means of a current of sulphur dioxide gas circulated through the vaporizer, then through a condenser, and back again through the vaporizer. The sulphur is condensed as a liquid, or flowers of sulphur may be obtained by varying the method of condensation of the vapor.

The solid material discharged from the base of the vaporizer consists of barium sulphite. At a temperature of 650° C. this is easily reduced to barium sulphide by treatment with hydrocarbon gas or carbon. The reaction is greatly accelerated by using finely crushed materials and by elevating the temperature above the point mentioned.

The reducer consists of a muffle roaster, the temperature on the floors of which is kept above 650° C. by direct firing through the muffles. The reducer may be operated under down draft, and hydrocarbon gas may be circulated over the floors on which the heated barium sulphide is rabbled. Coke or coal may be mixed with the barium sulphite and the reduction attained in this manner.

Heavy fuel oil may be mixed with the barium sulphite, and the reducer operated under down draft. If this is done, the reduction is performed partly by the residual carbon from the oil and partly by the vapor and gas given off by the decomposition of the oil. Any residual gas emerging from the lower floor may be burned directly in the muffles and the total oxygen combining power of the oil approximated without the use of a gas producer.

The "wet process" is applicable to any concentration of sulphur dioxide gas, as the excess oxygen is not absorbed by the water, and reducing fuel, which is the main item as to cost, is used in direct proportion to the sulphur produced.

APPLICATION OF "WET PROCESS."

The absorbing power of water varies almost directly with the concentration of sulphur dioxide in the gas. For this reason a highly concentrated gas is cheaper to handle, as the production of sulphur increases for the same absorption and circulation costs for power, labor, and installation.

The Thiogen process in its present form, as described above, has not as yet (May, 1914) been applied on a commercial scale. Experiments with an earlier form of the process were performed on a large scale at the smelter at Campo Seco, Cal.

PROPOSED PROCESSES FOR THE REMOVAL OF SULPHUR DIOXIDE.

USE OF LIME IN PRESENCE OF WATER.

If gases containing sulphur dioxide be brought into intimate contact with lime in the presence of water, the sulphur dioxide unites with the lime to form calcium sulphite. This can be accomplished by passing the gases containing the dioxide through towers filled with crushed limestone or with brush-wood layers, heavily sprinkled with lime, or through towers against a descending spray of milk of lime. According to Richards,[a] the Ashio copper smelter in Japan employs this method to neutralize sulphur dioxide in its smelter smoke. All of the sulphur trioxide is destroyed and the sulphur dioxide reduced from 0.8 to 0.5 per cent. However, the mechanical details of the process for the handling of enormous quantities of gas have never been worked out, nor has it been stated how the product, calcium sulphite, could be used locally. This method has been applied on a small scale at zinc smelters in Silesia, Germany, but holds forth no promise under present conditions in this country.

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[a] Richards, J. W., The Japan excursion of the American Institute of Mining Engineers: Met. and Chem. Eng., vol. 10, January, 1912, p. 21.

POSSIBILITY OF ABSORPTION IN WATER.

It has been suggested that sulphur dioxide may be removed by absorption in water. It is a well-known fact that the concentrated gas is highly soluble in water. At 32° F. and at standard atmospheric pressure 1 volume of water will dissolve 79.8 volumes of sulphur dioxide gas, which is equivalent to 1 cubic foot of water, or 62.5 pounds, dissolving 14.25 pounds of sulphur dioxide. The solubility decreases rapidly with rising temperature, and at 104° F. and standard pressure only 18.18 volumes of sulphur dioxide is dissolved by 1 volume of water. These data refer to pure sulphur dioxide gas.

PROPORTION OF SULPHUR DIOXIDE DISSOLVED BY WATER.

The proportion of sulphur dioxide gas dissolved by water from a mixture of gases, such as smelter smoke, depends on the partial pressure of the sulphur dioxide gas, which in turn depends on the proportion of the unit volume it occupies. As an example, if smelter smoke containing 3 per cent of sulphur dioxide (which is high) be submitted to the action of water at 32° F. and the atmospheric pressure is 650 mm., 1 volume of water will dissolve only 2.04 volumes of sulphur dioxide. If the smelter smoke contain only 0.75 per cent of sulphur dioxide, the water will dissolve only 0.56 volume of the gas. In actual experiments made by W. C. Ebaugh in Salt Lake City, it was found that smelter smoke containing about 1.5 per cent of sulphur dioxide, when submitted to the action of water at 95° to 102° F., gave rise to solutions containing 0.33 volume of sulphur dioxide per volume of water.

It is therefore plainly evident that not much may be expected from the endeavor to remove sulphur dioxide from ordinary metallurgical smoke by spraying it with water or passing it through water in in some manner. However, Ingalls[a] states this method is perfectly feasible for gases containing a considerable percentage of sulphur dioxide (4 per cent), and that it has been applied in practice in Silesia, Germany, at certain zinc smelters. The smoke would have to be submitted to a large number of consecutive washings, and the quantity of water necessary would be excessive.

REMOVAL OF SULPHUR DIOXIDE BY REFRIGERATING SMOKE.

Another suggestion is to freeze out the sulphur dioxide from smelter smoke by submitting the smoke to refrigeration. One proposal of this kind suggests that the smoke be submitted to such a low temperature that the sulphur dioxide will be precipitated either as liquid sulphur dioxide or as frozen dioxide. The impossibility of this plan has already been discussed under the properties of sulphur dioxide. A second proposal is to refrigerate the smoke in a manner similar to that employed at a few iron blast furnaces[a] for drying of air used in the furnaces. The air is passed through refrigerating chambers, where it deposits all moisture in excess of that which it can carry at the freezing point. If smelter smoke containing sulphur dioxide and water vapor is refrigerated, the product is ice that contains a certain proportion of a hydrate of sulphur dioxide. With water highly charged with sulphur dioxide this crystallohydrate of sulphur dioxide and water, of the composition SO_2+7H_2O, freezes out first. It contains 33.7 per cent sulphur dioxide and 66.3 per cent ice. If this ice containing the sulphur dioxide be melted and the resultant acid water heated in a vacuum, sulphur dioxide will be liberated in a concentrated form, which can be readily liquefied. The relation between sulphur dioxide and water, in reference to pressure, temperature, and concentration has been fully worked out by Roozeboom.[b] The cryohydrate, or the solution of water and sulphur dioxide having the lowest freezing point contains 92.1 per cent water and 7.9 per cent sulphur dioxide, freezing at −2.6° C. The difference between the freezing point of this cryohydrate and that of water is too small to permit, in a commercial operation, the obtaining of a concentrated liquid by the freezing of dilute solutions of sulphur dioxide and water.

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[a] Ingalls, W. R., The metallurgy of zinc and cadmium, 1905, p. 166.

COMMERCIAL APPLICATION OF REFRIGERATION PROCESS DOUBTFUL.

No data of experiments on a commercial scale are available as to the concentration of sulphur dioxide attainable in the ice formed from ordinary smelter smoke, but it seems questionable that this concentration can be high, when the small amount of sulphur dioxide actually dissolved by water from smelter smoke is considered. One of the difficulties of the process would be the disposal of the liquid sulphur dioxide. Manifestly it is impossible to discharge it into streams or onto the land, and unless a ready market be available it would seem that the process could not be applied commercially. The principles on which the process is based seem sound theoretically, but data on such necessary details as the amount of water needed and the attainable concentration of sulphur dioxide in the ice are entirely lacking.

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[a] The Gayley process.

[b] Roozeboom, H. W. B., Sur l'hydrate de l'acide sulfureux; Rec. trav. chim. Pays-Bas, vol. 3, 1994, p. 29; Sur la dissociation des hydrates de l'acide sulfureux, du chlore et du brome: vol. 4, 1885, p. 65; Sur les points triples et multiples, envisagés comme points de transition: vol. 6, 1887, p. 319; Studien über chemisches Gleichgewicht: Zeitschr. physikal. Chem., vol. 2, 1888, p. 450; quoted by Nernst, —, Theoretic chemistry, 1911, p. 622, and by Findlay, —, The phase rule, 1906, p. 169, and by Landolt and Börnstein, Physikalisch-chemische Tabellen, 1912, p. 493.

USE OF FINELY GROUND SLAG OR SLAG WOOL.

Westby and Sorenson have proposed a process whereby hot smelter smoke containing appreciable amounts of sulphur dioxide is brought into intimate contact with finely ground ferruginous slag, such as is produced in copper or lead smelting, resulting in the formation of iron sulphur salts, which dissolve in water, with the consequent elimination of the sulphur dioxide from the smoke stream. The slag, which is a waste product of the smelting, may be used either in a finely ground form or as slag wool, a product produced by blowing air or steam against a slag stream so that it is spun out into fine threads. In the experimental work the smoke stream from a roasting furnace was admitted into a wooden tower set in a water seal. The tower was provided with numerous sloping baffle plates. The water and finely ground slag charged from a hopper at the top spread over these baffles or shelves, the slag accumulating on the shelves, thus exposing large areas of material. The ascending smoke stream came into contact with this slag and the descending water sprays, resulting in the rapid chemical action of the sulphur dioxide on the iron silicates of the slag, with the formation of such salts as ferrous and ferric sulphites, ferrous sulphate, thionate of iron, and sulphur salts of other bases, such as lime. Some of these salts are dissolved by the water, whereas others remain as insoluble constituents with the undissolved slag residue.

RESULTS EXPECTED OF PROCESS.

In practice the solutions were to be discharged from the water seal and run into ponds, where oxidation of the iron sulphur salts would take place, precipitating iron oxides and basic sulphates, or they were to be run over waste lands where they would be absorbed by the soil and any acids present be neutralized by the lime constituents of that soil, so that the ground water would not be rendered impure. The slag used usually contained 0.2 to 0.4 per cent copper. In the slag wool this copper was in the form of oxide. In the finely ground slag the copper was partly in the form of oxide and partly in the form of sulphide. That part present as oxide of copper would dissolve and pass out with the solutions, whereas that present as sulphide would remain with the slag residues in the tower. The dissolved copper was to be precipitated from the solutions by heating them with steam, which would cause the thionates of iron present to react with the soluble copper salts to form insoluble copper salts. The slag residues from the tower containing the insoluble copper, owing to their relatively small bulk, might contain sufficient copper to warrant their resmelting in reverberatory furnaces. If the location of the smelting plant should justify it, such by-products as iron sulphate and zinc sulphate might be recovered from the solutions.

The process has been tried only experimentally, and, under favorable conditions, as much as 85 to 90 per cent of the sulphur dioxide is said to be removable from the smoke stream. It would seem that the process is applicable only to gases comparatively high in sulphur dioxide, containing, say, more than 4 per cent, and to comparatively small volumes of smoke. Its application to great volumes of gas comparatively low in sulphur dioxide seems hardly feasible.

DILUTION OF THE SULPHUR DIOXIDE BY AIR.

The dilution of smelter smoke by air to such a point that the concentration of sulphur dioxide is low enough to be considered harmless appears at present the only universally applicable remedy for the sulphur dioxide nuisance. Although this fact is generally known and its significance is fully realized by metallurgists, it would seem that in a number of instances the possibilities of the method have not been fully utilized.

USE OF HIGH CHIMNEYS NOT SATISFACTORY.

It was formerly rather generally believed that if smelter smoke was discharged from high chimneys natural diffusion would so act on the smoke stream that when the gases reached the ground, the sulphur-dioxide would be so diluted as to be practically harmless. However, experience, both in this country and in Europe, does not warrant this assumption. It seems rather that the diffusive action is comparatively slow, and that frequently masses of smelter smoke are wafted to the surface, still in such concentrated condition as to be harmful. High stacks tend to protect the immediate vicinity around the smelting plant, and may cause a milder but rather widespread damage at some distance from the plant. Of course in considering whether damage will be done, it is necessary to know the initial concentration of the sulphur dioxide as it issues from the stack. If this be low, say less than 1.50 per cent, the great probabilitiy is that with a high stack diffusion will be sufficient to render the discharge practically harmless. If, however, the concentration of sulphur dioxide is greater than this, there is a possible chance of damage being done. Court decisions in California and Utah have set 0.75 per cent as the maximum permissible sulphur dioxide content of smoke streams discharged by smelter stacks. This figure is not based on scientific experiment, but was adopted as a general figure to conform to certain opinions held at the time the decisions were rendered.

USE OF FANS GIVES PROMISE.

Recently the feasibility of diluting the smoke stream with air by the use of large fans and of then discharging the diluted smoke from a number of low stacks rather than from one high stack has received considerable attention. One case in point is the manner of discharging smelter smoke in use in the plant at Kennett, Cal., which has been described. There fans are in use for the special purpose of diluting the smoke stream with air. The copper-smelting plant at Coram, Cal., before its shutdown, also employed fans for the dilution of the smoke stream.

It has recently been stated that the Ashio Copper Co., in Japan, will use a similar system.[a] At this plant the problem of fume damage is important, and the proposed method of the disposal of the smelter smoke was adopted after careful study of conditions the world over. It is proposed to proceed as follows: (1) To cool the smoke stream by radiation to 100° C. or less; (2) to settle the fine dust by passing the smoke stream through a chamber 210 feet long at a velocity of 3 feet per second, the dust chamber to be hung with bamboo strips instead of wires; (3) to dilute the smoke stream to 0.3 per cent sulphur dioxide or less with fresh air by means of fans, and to scatter the diluted smoke by the use of three or four stacks rather than one stack.

LEGAL ASPECT OF THE SMELTER-SMOKE PROBLEM.

Although the smelter-smoke problem has been in the courts for a long time in a minor way, it has been prominent only in the past 10 years. During that time, however, and at present it is attracting nation-wide attention. The cases that have been before the courts may be classified geographically under five heads, as follows: (1) Utah, centering about Salt Lake City; (2) southeastern Tennessee, near the Georgia and North Carolina boundary line; (3) Montana, centering about Butte and Anaconda; (4) Shasta County, Cal.; (5) near San Francisco, Cal., in Contra Costa and Solano counties. There are cases of minor importance in other sections of the country, but those in the five localities mentioned serve well to illustrate the legal aspects of the smelter-smoke problem.

UTAH CASES.

The country about Salt Lake City contains rich agricultural lands, particularly along the Jordan River. Many years ago, during the early mineral development of Utah, various smelters were erected in the midst of this section, and grew into large plants. There was always more or less trouble between individual farmers and certain smelting companies which was adjusted by the payment of damages. The early smelters treated lead ores. Later, copper smelters were built and the complaints about smoke became more insistent. In 1901, and immediately before that, certain farmers obtained heavy damages from one of the smelting companies on account of injury to crops. Damage did not cease, and in 1904, after lengthy conferences between the farmers of the vicinity and various smelting corporations, which led to no results, suits were started against the smelting companies.

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[a] For description of this system see editorial, Dust chambers at the Ashio smelter, Japan: Min. Sci. Press, vol. 109, January, 1914, p. 13.

In the case of James Godfrey et al., representing about 400 farmers, versus the American Smelting & Refining Co., the United States Smelting Co., the Bingham Consolidated Co., and the Utah Consolidated Co., the Federal court issued an injunction in November, 1906, designed to prevent any of the companies from treating ore containing more than 10 per cent sulphur in the natural state, or permitting the escape of arsenic from the stacks. This decision was upheld on appeal. The Bingham Consolidated Co. and the Utah Consolidated Co. then abandoned their smelters. The American Smelting & Refining Co., by permission of the court, entered into contract with the farmers to rebuild its flue and dust-chamber system and to add a bag house for the filtering of blast-furnace gases at its Murray plant, and was permitted to resume operations. The United States Smelting Co., at Midvale, also entered into an agreement with the farmers by permission of the court, and built elaborate bag houses for the filtering of gases from all of its furnaces in the lead department. The agreements reached called for (*a*) the removal of all free sulphuric acid in the smelter smoke; (*b*) the removal of all solids from the smoke by means of a bag house; (*c*) that after the removal of solids and sulphuric acid, the gases discharged into the atmosphere should contain not more than 0.75 per cent of sulphur dioxide; (*d*) that such sulphur dioxide as escaped should not damage crops and live stock or cause discomfort or inconvenience to persons. Under this agreement the United States Smelting Co. resumed operations in its lead department in April, 1908. The copper department of the smelter has not as yet resumed operations, although granted permission to do so. All of the copper smelting of the Salt Lake Valley is now done at Garfield and at Tooele, westward from Salt Lake City, in a region where smoke can seemingly do less damage than in the immediate vicinity of Salt Lake City. Although at present there is not much complaint about smoke near Salt Lake City, it is doubtful whether the matter is permanently settled.

TENNESSEE CASES.

The copper smelters of the Tennessee Copper Co. and of the Ducktown Copper, Sulphur & Iron Co., are at Copperhill and Isabella, respectively, in the extreme southeastern corner of Tennessee, less than a mile from Georgia and only a few miles from North Carolina. The country is beautiful, mountainous, and heavily wooded, although in places it is well cultivated. The prevailing winds for the greater part of the year blow to the south. The country immediately surrounding Copperhill and Ducktown is entirely denuded and bare, the damage having been wrought largely during earlier days when heap roasting was extensively practiced. There was always more or less trouble in the district, particularly in northern Georgia. In May, 1907, the State of Georgia obtained from the Supreme Court of the United States the permission to call for a permanent injunction restraining the Tennessee Copper Co. and the Ducktown Copper, Sulphur & Iron Co. from operating their plants. This injunction, however, was not put into effect because the companies were constructing sulphuric acid plants for the treatment of the smelter smoke. This method was put into successful operation, and former difficulties have largely disappeared. However, the sulphuric acid plants are not large enough to fully accommodate the tonnage that might be smelted, and the Tennessee Copper Co. is forced during the active crop-growing season to curtail its tonnage in order not to produce damaging smoke. That some damage was perhaps still being done was reflected in a news statement dated October 25, 1913, that the Ducktown mine owners had contracted with the State of Georgia to pay annually $16,500 to Georgia farmers.

MONTANA CASES.

The great smelting interests of the State of Montana center about Anaconda, 29 miles west of Butte, Great Falls, 120 miles northeast of Butte, and East Helena, 50 miles northeast of Butte. The Montana smelter cases relate solely to the Anaconda location. The tremendous devastation wrought by sulphurous gases in the immediate vicinity of Butte, in the early days of smelting operations is well known. Damage was also done in the vicinity of Anaconda in the Deer Lodge Valley before the great copper smelter of the Anaconda Copper Mining Co. moved to its present site. It was claimed that this last plant also caused damage, and this complaint culminated in the suit of F. J. Bliss versus the Anaconda Copper Mining Co. and the Washoe Copper Mining Co.

A perpetual injunction was sought on account of damage by fume. In the first decision of the Federal court in January, 1909, the injunction was refused, although Bliss was awarded nominal damages, the court finding that some damage had been done by fume in the immediate vicinity of the smelter, but that no damage had resulted from sulphur dioxide. It decreed a rehearing of the case to determine whether the arsenic in the fume could be reduced in quantity. In May, 1911, the United States Circuit Court of Appeals confirmed the first decision, the records in the case being the most voluminous known in a suit of this kind, comprising more than 25,000 pages. Appeal was then had to the Supreme Court of the United States, which, in November, 1913, finally dismissed the suit. The United States Government, in 1910, also entered suit against the Anaconda Copper Mining Co. on account of damage by smoke to the national forests. This suit was not proceeded with, but a commission to investigate the matter was appointed in 1911, by agreement between the Department of Justice and the attorneys for the Anaconda Co. This commission consists of J. A. Holmes, Director of the Bureau of Mines, L. D. Ricketts, an eminent metallurgical engineer, and John Hays Hammond, the well-known mining engineer. Chemists and engineers employed by this commission are working in conjunction with employees of the Anaconda Copper Mining Co., seeking a solution of the smelter-smoke problem, and it is understood that good progress is being made.

SHASTA COUNTY, CAL., CASES.

The copper-smelting plants of Shasta County, Cal., are situated in the mountains immediately above the head of the great Sacramento Valley. The country immediately surrounding the various smelting plants has been entirely denuded by former operations. The section can not be called an agricultural one, but the Sacramento Valley lying below it is fertile and highly cultivated, and the complaint against the smelters arises chiefly from the farmers of that vicinity. The first plant to be closed down was that of the Mountain Copper Co., which was enjoined by the United States Government for doing smoke damage to forest reserves. Suit was brought by the Shasta County Farmers' Protective Association against the Mammoth Copper Co. at Kennett, a subsidiary concern of the United States Smelting, Refining & Mining Co., and the Balaklala Consolidated Copper Co. at Coram, seeking to enjoin these companies from operating. The case was brought to trial and the United States circuit court of appeals, in February, 1910, arranged for agreements between smelters and farmers whereby the smelters were permitted to operate provided that they fulfilled conditions similar to those outlined for the United States Smelting Co. in Utah. In confirmation with this agreement the Mammoth Copper Co. put in a bag house and diluting fans, and the Balaklala Co. installed the electrical precipitation process and diluting fans, and the companies continued to operate. Some time later the Balaklala Consolidated

Copper Co. decided to close its plant as damage to crops was still found to continue. The Mammoth Copper Co. is still operating, being able to satisfy the conditions imposed. The difficulty, however, is by no means settled, and it is stated (December, 1913) that the Farmers' Protective Association expects to proceed again against the smelting company. In November, 1913, the governor of California appointed a commission consisting of the secretary of the State board of health, the horticultural commissioner, and the State veterinarian to investigate the smelter fumes. It is hoped that this commission will assist in solving the problem. In 1910 the Government suggested to the officials of the Bully Hill Smelter, in this vicinity, that they begin vigorous experimental work for the abatement of the smoke nuisance on account of damage then being done to forest reserves. The company thereupon closed its plant in order to be better able to work out its problems and devise new methods.

Since the Government is interested in this section of California by virtue of the forest reserves, the secretary of the commission that has charge of the Montana smelter-smoke cases, J. A. Holmes, has several times visited this district.

CASES NEAR SAN FRANCISCO.

A number of smelting and acid plants are located in Contra Costa County, on San Pablo Bay, near San Francisco. These are the Selby Smelting & Lead Co., the General Chemical Co., and the Mountain Copper Co. During the past 9 or 10 years there has been difficulty in this district owing to claims of damage by farmers in Contra Costa and Solano Counties. Suits in the local and State courts were frequent. Statutes seeking to regulate the disposal of smelter smoke were passed by county supervisors. The situation is complicated by the existence in the vicinity of other manufacturing plants, which give rise to odors and gases of a disagreeable nature. It seems, however, that the smelting plants receive most of the blame, possibly unjustly.

In 1908 the Selby Smelting & Lead Co. was enjoined by the superior court of the State from operating the smelter during the period from March 15 to October 15 of each year. In this time the trade winds carry the smoke westward across the Karquines Straight to Benicia and the adjoining farm lands. Since then the company has installed one bag house for its blast-furnace gases and another for those of the Dwight-Lloyd sintering machines and has put in the electrical-precipitation process for the condensation of acid fume from the parting kettles. It has also diverted ores high in sulphur to the General Chemical Co.'s plant at Bay Point, where the sulphur is utilized in the manufacture of sulphuric acid, the roasted ore being returned to the Selby smelter. The introduction of these improvements has much ameliorated the conditions that formerly existed. The complaints from the farmers, however, have not entirely ceased, and in March, 1913, the county supervisors of Solano County and the officials of the Selby Smelting & Lead Co. agreed on the appointment of a commission of three experts to investigate and decide future questions of annoyance and nuisance resulting from the escape of smelter fumes. This commission consists of J. A. Holmes, Director of the Bureau of Mines; E. C. Franklin, of the department of chemistry, Stanford University; and Ralph A. Gould, a chemical engineer of San Francisco. It has conducted a long and thorough investigation and in November, 1914, submitted its report, which is to be published as soon as practicable.

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